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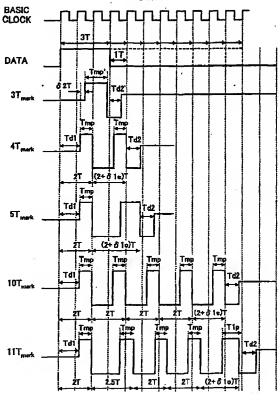
(54) Information recording method information recording apparatus and optical information recording medium

(57) An information recording technique for forming a recording mark with a multi-pulse sequence, which is increased by one pulse with an irradiation power Pw for every increase of 2T in a temporal length nT of the recording mark is provided. Particularly, this technique realizes a recording strategy that is simple in its configuration but is. capable of improving the consistency of mark shapes in forming the recording marks when the value n of the temporal length nT is an odd number. More specifically, when n is an odd number and $n \geqq 7$, a period from the fall of a first pulse to the fall of a second pulse is set to 2.5T and a period corresponding to a last pulse is set to $(2+\delta_1 o)T$ where the value of $\delta_1 o$ is optimized within a range of $0 < \delta_1 o \leqq 1$. In this way, the multi-pulse sequence can be adjusted from the front pulse side and the rear pulse side so that an overall consistency can be realized in the mark shape upon recording the mark. At the same time, when $n \geqq 4$, the fall of the first pulse is synchronized with a basic clock, and the fall of the second pulse and the rest of the pulses except for the last pulse are also synchronized with the basic clock by irradiating the pulses at periods of 2.5T or 2T. In this way, the design of a recording strategy generation circuit that generates the actual recording strategy can be simplified.

FIG.4



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Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] The present invention relates generally to an information recording method, an information recording apparatus, and an optical information recording medium. More particularly, the present invention relates to an information recording method suitable for recording information on a phase change optical information recording medium such as a CD-RW, a DVD-RAM, a DVD-RW, or a DVD+RW using an information recording apparatus.

2. Description of the Related Art

[0002] In recent years, there has been a growing demand for high speed recording on an optical information recording medium. In turn, technologies for increasing the recording speed of the disk type optical information recording medium are rapidly developing since the recording/reproducing speed in this type of optical information recording medium can be increased by simply increasing its rotational speed. Particularly, an optical disk (disk type optical information recording medium) that can record information simply through intensity modulation of light that is irradiated upon recording is becoming increasingly popular these days. The simplicity of the recording mechanism of this type of optical disk enables a reduction of cost of the recording medium as well as the recording device. Also, since the intensity-modulated light is also used in the reproduction of the information, excellent compatibility can be realized with a reproducing-only apparatus. With the increase in the capacity of electronic information in recent years, there is presently an even greater demand for higher density and higher speed in the information recording technology.

[0003] The above described optical disk that is further characterized by using a phase change material is becoming the mainstream optical recording medium since it can be rewritten numerous times. In the optical disk using the phase change material, recording is performed by modulating the intensity of the irradiated light beam and creating a rapidly cooled state and a slowly cooled state in a recording layer material. When the recording layer material is rapidly cooled, an amorphous state is created, and when it is cooled slowly, a crystalline state is created. Thus, optical information can be recorded owing to the difference in optic physical properties between the amorphous state and the crystalline state.

[0004] The recording principle of the above optical disk uses complicated mechanisms of 'rapid cooling' and 'slow cooling' of the recording layer material. Thus, in high speed recording, the recording light undergoes a pulse division and a three-level intensity modulation to then be irradiated onto the recording medium. For example, this recording method is disclosed in Japanese Patent Laid-Open Publication No.9-219021, Japanese Patent Laid-Open Publication No.9-138947, Recordable Compact Disc Systems Part III ("Orange Book Part III") version 2.0, Recordable Compact Disc Systems Part III ("Orange Book Part III") Volume 2 version 1.1, and DVD+RW Basic Format Specifications version 1.1.

[0005] FIGS.1A-1D are diagrams for illustrating the above recording method, wherein a mark shown in FIG.1A is turned into data as shown in FIG.1B where marked portions correspond to 'High' and unmarked portions correspond to 'Low'. The above recording method is suitable for use in mark length recording or mark space recording. The mark has a temporal length that is an integer multiple of a basic clock period T. That is, the mark to be recorded has a temporal length nT where n is a natural number. The value range for the natural number n varies depending on the modulation method. In a compact disk system, n is within a range of 3-11. In a DVD system, n may take a value within the range of 3-11 or 14. In this drawing, n is set to n=6.

[0006] In the above described prior art, in order to form a mark with a temporal length of nT, an m number of multi pulses are irradiated as shown in FIG.1C. The number m depends on the value of n, and their relationship is either m=n-1 or m=n-2. This is because the minimum value of n in a CD or DVD is 3. Also, an irradiation period of the pulse, that is, the rise period of each pulse is 1T, as shown in FIG.1C where m=n-1, and in FIG.1D where m=n-2. However, in either case, the period and width of a first pulse is independently set.

[0007] This recording method is characterized in that an increase of 1T in the mark length can be accommodated simply by adding one more pulse, and is thus very suitable for mark length recording.

[0008] However, when the recording speed is increased, the basic clock frequency increases. For example, in a 24× high-speed CD-RW, the basic clock frequency is 104 MHz, and in a 5× high-speed DVD-RW or DVD+RW, the basic clock frequency is 131 MHz. Thus, when recording is performed according to the conventional recording method (recording strategy) in these cases, the rise time and fall time of the pulse will take up a large portion of the total pulse irradiation time thereby decreasing the effective irradiation light energy, namely, the integration value.

[0009] FIGS.2A-2C are exemplary diagrams illustrating the above effect. In these drawings, the dotted lines show the ideal irradiation waveforms and the solid lines show the actual light emission waveforms. In FIG.2A, the actual light

emission waveform is not rectangular as indicated by the dotted lines because of the time required for the rise and fall of the pulse. Thus, the pulse has a waveform as indicated by the solid line. When the basic clock is sped up further so that the rise time and fall time take up an even larger portion of the total irradiation time in the basic clock period, the irradiated pulse will be unable to reach a sufficiently high peak power Pw and a sufficiently low bottom power Pb as shown in FIG.2B. That is, the peak power Pw will be Δ Pw lower and the bottom power Pb will be Δ Pb higher than the desired level. When the peak power Pw is lowered, there will be a decrease in the volume of material that can rise in temperature to a level sufficient for the material to turn amorphous. Also, when the. bottom power Pb is not low enough, rapid cooling will be hampered thereby causing a re-crystallization of the material. This causes a decrease in the reproduction signal amplitude leading to a significant degradation of the reproduction reliability.

[0010] In order to solve the above described problem, a light source (laser diode and its drive unit) that can realize light emission with a short rise time and fall time is needed. However, to effectively function with a frequency above 100 MHz, the rise. time and fall time need to be below 1 ns, which is very difficult to realize with the present technology.

[0011] Thus, in Japanese Patent Laid-Open Publication No.9-134525 and in U.S. Patent Application No.5732062, a technology for high speed recording using the conventional light emission source is disclosed. According to these prior art inventions, the number of irradiated recording pulses are reduced so that the mark having a length that is n times the basic clock period T, that is, the mark with a temporal length of nT, is formed through irradiation of m pulses where n=2m when n=even number, and where n=2m+1 when n=odd number, as opposed to the conventional art where n-1 pulses are irradiated for the same mark. For example, in a CD-RW that uses the EFM modulation (Eight to Fourteen Modulation; 8-14 modulation), n is a natural number within a range of 3-11. Thereby, in the conventional art when n=3, 4, 5, 6, 7, 8, 9, 10, and 11, the corresponding irradiation pulse numbers are: 2, 3, 4, 5, 6, 7, 8, 9, and 10, respectively. On the other hand, according to the methods disclosed in Japanese Patent Laid-Open Publication No.9-134525 and U.S. Patent Application No.5732062, when n=3, 4, 5, 6, 7, 8, 9, 10, and 11, the corresponding irradiation pulse numbers are: 1, 2, 2, 3, 3, 4, 4, 5, and 5, respectively. In this way, the pulse number can be reduced approximately by a half of the number of pulses used in the conventional art. Accordingly, the irradiation time of one pulse changes from 0.5T for the irradiation of n-1 pulses to 1T, which is double the conventional irradiation time, so that influence from the rise time and fall time can be reduced.

[0012] On the other hand, since the same number of pulses (m pulses) are irradiated to form recording marks with differing lengths 2mT and (2m+1)T, the irradiation period cannot be fixed. That is, when forming a recording mark with a length nT when n=2m, an irradiation time (the time when P=Pw) and a cooling time (the time when P=Pb) of a given pulse has to be made shorter compared to a case in which a recording mark with the length nT when n=2m+1 is recorded.

[0013] In Japanese Patent Laid-Open Publication No.2001-331936, a recording method using an m number of multi-pulses for forming a recording mark with a temporal length of nT wherein n/m≧1.25 is disclosed. As in the above Japanese Patent Laid-Open Publication No.9-134525, this patent application also describes the technology for recording marks with differing temporal lengths nT both when n=2m and n=2m+1 by irradiating the same number of pulses (m pulses). Herein, the irradiation time of the pulse is adjusted by modifying the irradiation time and cooling time of the first pulse and last pulse.

[0014] However, basically, according to the above methods, the irradiation time and the cooling time of all the pulses for each of the various mark lengths have to be defined. In turn, 69 parameters will be needed in the EFM (8-14 modulation) that is used in a compact disk and 77 parameters will be needed in a EFM+ (one type of the 8-14 modulation) used in a DVD. Thus, various techniques for reducing the number of parameters needed for defining the pulses are being proposed. For example, the irradiation time of a first pulse when m≧3 can be made to conform to a uniform length instead of being based on n, or the irradiation time and the cooling time of the middle pulses (the pulses other than the first and last pulses) can be made to conform. However, in the above examples, when m=1 or 2, that is, when n≦5, the parameters have to be set individually for each case. Therefore, a very large number of parameters will still be needed for defining the recording light emission waveform (recording strategy). Further, when the recording speed (scanning velocity) varies, a different recording pattern is needed for each recording speed. In such case, the irradiation time when P=Pw (i.e. the actual time of the pulse width as opposed to the relative time with respect to the clock period that can change depending on the recording speed) can be made to have a uniform length regardless of the recording speed.

[0015] Also, in a WORM (write once, read many) optical disk or a rewritable optical disk as represented by the CD-R/RW or the DVD+R/RW, parameters relating to the recording conditions of the disk are normally preformatted on the disk itself. For example, the preformatted disk information may be in the form of ATIP (Absolute Time in Pregroove) Extra Information in a CD-R/RW, or ADIP (Address in Pregroove) Physical Information in a DVD+R/RW. The preformatted disk information includes basic features such as the type of disk and the version of the disk standard, parameters needed for calculating the recordable scanning velocity and the optimum recording power in a test recording, and parameters that specify the optimum recording strategy. As for the parameters that specify the optimum recording strategy, there are ε (=Pe/Pw), and Strategy Optimization (dT_{top}, dT_{era}) according to CD-RW standard specifications,

and T_{top}, dT_{top}, T_{mp}, dT_{era}, ε_1, ε_2, according to DVD+RW standard specifications.

[0016] The information recording apparatus reads the above information upon recording information on a disk, and determines the recording strategy. Thus, it is preferable that detailed parameters be provided so that the recording device can determine an accurate recording strategy. However, detailed parameters will lead to an increase in information capacity requirements. Particularly, in a CD-R/RW system, the information capacity for recording the preformatted information is limited and in the case of a CD-RW, information worth 21 bits × 6=126 bits is the maximum capacity for the preformatted information. To pre-format additional information, an area has to be newly defined in an unused area in either the outermost portion or the innermost portion of the disk such as the XAA (extra additional information area) in a multi-speed CD-R, or otherwise, the information has to be recorded using a pre-pit and the like.

[0017] As described above, the recording device reads the preformatted disk information upon recording information on the disk and sets the optimum recording strategy. When each disk has a large amount of parameter information, the processing of the information content becomes complex thereby causing the strategy generation circuit to be complicated.

[0018] Also, as mentioned earlier, it is preferable that the pulse irradiation time be arranged to be uniform. However, since marks with different lengths 2mT and (2m+1)T are recorded by irradiating the same number of m pulses, it is impossible to fix the irradiation period to a uniform time period. In the above case, when the irradiation period of a mark with length nT (where n=2m or n=2m+1) is set according to the value of n, the strategy generation circuit will be very complicated. That is, the irradiation period will have to be set individually for each case, and when the irradiation pulse timing is set individually as opposed to being in accordance with the basic clock timing, the circuit design becomes extremely complicated.

[0019] Also, under the restriction of having to record marks having differing lengths 2m and 2m+1 with the same number of m pulses, if the method according to the so-called "Orange Book Part III" is used, wherein only the pulse width of the last pulse is adjusted when the value n of the mark with length nT is an odd number, the difference in the irradiation between the last pulse and the rest of the pulses will be too distinct and the mark formed will not have a consistent shape (the mark corresponding to the last pulse is likely to become larger). As a result, reproduction signals for this recording mark will have a distorted waveform, causing an increase in the generation of jitters.

[0020] Also, for the reasons described above, the determination of the recording strategy is preferably realized with few parameters but with accuracy.

SUMMARY OF THE INVENTION

[0021] It is an object of the present invention to provide an information recording method, an information recording apparatus and an optical information recording medium in compliance with a recording technique for forming a recording mark with a multi-pulse sequence, which is enhanced by one irradiation power Pw pulse for every increase of 2T in a temporal length nT of the recording mark, this recording technique being applicable to high speed recording, wherein distortion of the waveform of a reproducing signal for the recording mark can be reduced by determining a recording strategy that can realize improved consistency in the shape of the recording mark being formed when the value n of the mark length nT is an odd number.

[0022] Also, it is an object of the present invention to provide an information recording method, an information recording apparatus and an optical information recording medium in compliance with a recording technique for forming a recording mark with a multi-pulse sequence, which is enhanced by one irradiation power Pw pulse for every increase of 2T in a temporal length nT of the recording mark, this recording technique being applicable to high speed recording, wherein the circuit design for realizing the above technique can be simplified.

[0023] Additionally, it is an object of the present invention to provide an information recording method, an information recording apparatus and an optical information recording medium in compliance with a recording technique, wherein only a few parameters are set to determine an optimum recording strategy for a plurality of scanning velocities as opposed to a recording technique for high speed recording that uses a large number of parameters to determine a complex recording strategy.

[0024] More specifically, the present invention provides an information recording method for recording information on an optical information recording medium using a mark length recording scheme in which a temporal length of a recording mark is represented as nT where n denotes a natural number and T denotes a basic clock period, wherein:

the recording mark is formed by a multi-pulse sequence, which is increased by one pulse with an irradiation power Pw for every increase of 2T in the temporal length nT; and
a recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that:

when $n \geqq 4$, the fall of a first pulse of the multi-pulse sequence is synchronized with the basic clock; and
when n is an odd number and $n \geqq 7$, a period from the fall of the first pulse to the fall of a second pulse in the

multi-pulse sequence is arranged to be greater than 2T and in synchronization with the basic clock, periods of pulses after the second pulse except for a last pulse of the multi-pulse sequence are arranged to be 2T, and a period from a fall of a second to last pulse to the fall of the last pulse, denoted as T_1o, is set to $T_1o=(2+\delta_1o)T$ where $0<\delta_1o\leqq 1$.

[0025] According to another aspect, the present invention provides an information recording apparatus that records information on an optical information recording medium according to a mark length recording scheme in which a temporal length of a recording mark is represented as nT where n denotes a natural number and T denotes a basic clock period, the information recording apparatus comprising:

a rotational drive structure that rotates the optical information recording medium;
a laser light source that generates a light beam, which is irradiated on the optical information recording medium;
a light source drive unit that administers the laser light source to emit light;
a light emission waveform control unit that controls the light source drive unit when a recording strategy relating to a light emission waveform of the light beam generated by the laser light source is set; and
a speed control unit that controls a relative scanning velocity between the rotation of the optical information recording medium and the light beam irradiated on said optical information recording medium, wherein:

the light emission waveform control unit uses the recording strategy to control the light emission waveform so that:

when $n\geqq 4$, the fall of a first pulse of the multi-pulse sequence is synchronized with the basic clock; and when n is an odd number and $n\geqq 7$, a period from the fall of the first pulse to the fall of a second pulse in the multi-pulse sequence is arranged to be greater than 2T and in synchronization with the basic clock, periods of pulses after the second pulse except for a last pulse of the multi-pulse sequence are arranged to be 2T, and a period from the fall of a second to last pulse to the fall of the last pulse, denoted as T_1o, is set to $T_1o=(2+\delta_1o)T$ where $0<\delta_1o\leqq 1$.

[0026] Further, the present invention according to another aspect provides an optical information recording medium on which information is recorded using the information recording method according to the present invention wherein:

Information of δ_1o as a parameter for determining the time T_1o is preformatted on the optical information recording medium.

BRIEF DESCRIPTION OF THE DRAWINGS

[0027]

FIGS.1A-1D show exemplary waveforms of a recording strategy according to the related art;
FIGS.2A-2C show ideal irradiation waveforms and the actual light emission waveforms;
FIG.3 shows exemplary waveforms of recording strategies according to an embodiment of the present invention;
FIG.4 shows extractions of waveforms corresponding to the recording strategies for marks with various lengths;
FIG.5 shows the relationship between a last pulse and a mark deviation;
FIG.6 shows the relationship between a pulse other than the last pulse and the mark deviation;
FIG.7 shows how duty of an irradiation time changes in response to a change in a scanning velocity;
FIG.8 shows functions that change the duty of the irradiation time in response to the change in the scanning velocity;
FIG.9 shows a plan view of an area distribution of an optical information recording medium;
FIG.10 shows a cross-sectional view of the structure of FIG.9;
FIG.11 shows a data format of an ATIP frame;
FIG.12 shows pre-format areas assigned to each parameter in an address information portion;
FIG.13 shows examples of pre-formatted bit information;
FIG.14 shows a conversion table for a parameter T_{d1};
FIG.15 shows a conversion table for a parameter T_{d2};
FIG.16 shows a conversion table for a parameter T_{d2}';
FIG.17 shows a conversion table for a parameter T_{mp};
FIG.18 shows a conversion table for a parameter T_{mp}';
FIG.19 shows a conversion table for a parameter δ_1o;
FIG.20 shows a conversion table for a parameter δ_2;

FIG.21 shows a conversion table for a parameter δ_3;

FIG.22 shows a flowchart of a recording strategy generation process;

FIG.23 is a block diagram showing a configuration of an information recording apparatus; and

FIG.24 shows exemplary waveforms of recording strategies according to a modified embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028] In the following, preferred embodiments of the present invention are described with reference to the accompanying drawings.

[0029] An embodiment according to the present invention is applicable to an information recording method and an information recording apparatus (including an information reproducing apparatus) for an optical information recording medium, particularly, a phase change optical information recording medium, on which information can be recorded, erased, or rewritten through intensity modulation of an irradiated light.

[0030] Recording on an optical information recording medium is realized by irradiating and scanning an intensity-modulated light beam and forming a recording mark on the recording medium. The recording mark is formed on a recording layer of the recording medium through the light irradiating on an area that differs in optical characteristics from the rest of the layer portion. The information recording/reproducing apparatus reproduces the recorded information based on the difference in optical characteristics of this recording mark portion. The state of the recording mark portion varies depending on the type of recording layer material used. In a case where a magnetic recording layer material is used, the recording mark portion is an area that differs in the magnetic field orientation, and in a case where a phase change recording layer material is used, the recording mark portion will be an area that has a different phase. In a rewritable optical information recording medium that uses the phase change material, which is currently the most popular recording medium, the recording layer material includes a crystalline phase and an amorphous phase (non-crystalline phase). Examples of the phase change recording layer material are SbTe alloy, GeSbTe alloy, AgInSbTe alloy, and GaGeSbTe alloy. In the phase change recording layer material, the crystalline phase and the amorphous phase have very different optical properties, and thus, information can be recorded by forming an amorphous phase mark in the crystalline phase. Further, if a reversible phase transition between the crystalline phase and the amorphous phase can be realized, the recording medium will be a rewritable optical information recording medium.

(Information Recording Method)

[0031] To form an amorphous mark in a crystalline phase, light condensed at the recording layer or its surrounding area is irradiated and scanned. As described above, an intensity modulated light beam is used for the irradiation. FIGS. 3 and 4 show light emission waveforms (recording strategies) using intensity modulation, which is a prerequisite of the embodiment of the present invention. At the top of FIG.4, information that is to be recorded, indicated as 'DATA', is shown. According to the information recording method of the present embodiment, information is recorded through mark length/mark space length modulation, which is a PWM (Pulse Width Modulation) technique applied to an optical information recording medium. In this recording technique, the length of the recording mark and the length of a mark space (blank space) are controlled by a unit T, which is the basic clock period. According to this technique, the recording density can be increased compared to a mark position modulation technique, which is another recording technique for an optical information recording medium. Thus, the mark length/mark space length modulation is used in optical disks such as the CD and DD (Double Density) CD, which use the EFM (8-14 modulation) scheme or the DVD, which uses the EFM+ (8-14+ modulation) scheme. In the mark length/mark space length modulation, it is important to accurately control the length of the mark and the length of the mark space. Specifically, both the mark and the mark space must have a temporal length of nT where T is the basic clock period and n is a natural number.

[0032] In FIG.4, the horizontal axis represents the temporal length, and the vertical axis represents either the information that is to be recorded (for the 'DATA') or the intensity of the irradiated light (for marks 3T, 4T, 5T, 10T, and 11T). The sections of the 'DATA' positioned at a 'High' (see FIG.1B) level correspond to the mark portion. Since FIGS.3 and 4 show exemplary waveforms obtained from the EFM (8-14 modulation) or the EFM+ (8-14+ modulation), n takes a value within the range of 3-11 or 14. FIG.4 shows extractions of the recording strategy when n=3, 4, 5, 10, and 11. The recording strategy when n=10 shown in FIG.4 is a representative example of the recording strategy in cases where n is an even number that is greater than or equal to 6 ($n \geqq 6$). On the other hand, the recording strategy when n=11 is a representative example of the recording strategy in cases where n is an odd number that is greater than or equal to 7 ($n \geqq 7$). As mentioned above, the vertical axis represents the intensity of the irradiated light (irradiation power) P. The intensity of the irradiated light or the irradiation power takes either one of three values Pw, Pe, and Pb, and the relationship between the three values is: Pw>Pe>Pb. Hereinafter, Pw will be referred to as 'recording power', Pe will be referred to as 'erasing power', and Pb will be referred to as 'bias power'. When a light beam is irradiated at P=Pe, the

phase change recording layer will be turned into a crystalline state. That is, the mark will be erased (a mark space is recorded). On the other hand, when light is irradiated with an intensity modulation of P=Pw or P=Pb, the phase change recording layer will be turned into an amorphous state. That is, a recording mark will be formed. The powers (light intensities) of Pw, Pe, and Pb are determined based on the thermal characteristics and optical characteristics of the recording phase material of the recording medium. However, it is preferable that the erasing power Pe be within a range of 0.2-0.6 w, and the bias power Pb be within a range of 0-0.1 w.

[0033] The recording strategy according to the present embodiment uses each of an m number of on pulses with the power P=Pw and an m number of off pulses with the power P=Pb. The relationship between n and m is such that when n is an even number n_1, n_1=2m, and when n is an odd number n_2, n_2=2m+1. Consequently, the recording mark is formed by a multi-pulse sequence that has each of one on pulse and one off pulse added for every increase of 2T in the temporal length nT. Herein, the pulse width (irradiation time) of the i^{th} (i=1,...,m) on pulse (P=Pw) for forming a recording mark with a temporal length of nT is denoted as T_{on}(n, i). According to the present embodiment, the pulse period can be approximately doubled compared to the pulse period obtained using the conventional m=n-1 recording strategy in a CD-RW, DVD-RW, and DVD+RW. As a result, the length of T_{on}/T can be increased and the influence from the rise time and fall time of the power P can be reduced in relative terms. Thereby, the present embodiment can be applied to high speed recording in which the basic clock period is shortened.

[0034] In the present embodiment, the irradiation time is not fixed and can be arbitrarily set; however, it is preferable that it be within a range of 0.5-1.5T. That is, when the irradiation time is shorter than 0.5T, the time is too short to supply sufficient energy to the recording layer, thereby causing the width of the recording mark to be narrowed, the amplitude of the recording signal to be reduced, and the modulation capacity to be lowered so that the reproducing reliability of the recording medium is degraded. On the other hand, when the irradiation time T_{on} is longer than 1.5T, the time when the power P=Pb becomes relatively short, thereby making it difficult to maintain a rapid cooling state. As a result, although sufficient energy can be supplied to the recording layer, the size of the recording mark is reduced due to re-crystallization. Further, since the absolute amount of energy charged on the recording medium is increased, thermal damage is created in the recording layer and its surrounding areas when recording and rewriting (overwriting) is performed numerous times, this resulting in the degradation of the reliability of the recording medium.

[0035] In the recording strategy according to the present embodiment, the irradiation time of the m^{th} pulse (the last pulse), that is, T_{on}(n, m), exerts the greatest influence on the length of the mark that is to be recorded. This is particularly the case when n=n_2 (odd number). In FIG.5, the relationship between the irradiation time T_{on}(n, m) and the mark deviation is shown. The mark deviation D(n) can be represented by the formula D(n)=L(n)-nT, wherein L(n) denotes the reproduced mark length. That is, when D(n)=0, this means that there is no difference between the logical mark length and the actual mark length, and thus the desired mark length can be reproduced. When n is an odd number (n=2m+1), the irradiation time T_{on}(n, m) becomes more dependent upon D compared to the case when n is an even number (n=2m). This is because marks having differing lengths n_1·T and n_2·T are recorded using the same number of pulses (m pulses). Since the mark length n_2·T is 1T longer than the mark length n_1·T, this difference needs to be compensated for by the pulse interval (irradiation period of each pulse) and the irradiation time T_{on}(n, i) of each pulse.

[0036] The pulse irradiation period is a factor influencing the consistency of the mark shape. When the pulse irradiation period of each pulse is not uniform, the shape of the recording mark is more likely to be distorted and as a result, the reproduced signal will also be distorted and jitter characteristics will be degraded (jitter will increase). This tendency is particularly evident in a case where the pulse irradiation time T_{mp} is short, that is, a case where the pulse width for P=Pw is short and the time when P=Pb is relatively long.

[0037] Therefore, it is preferable that the pulse irradiation period of each pulse be uniform. Further, it is preferable that this uniform pulse irradiation period be approximately nT/m. However, when the pulse period is set according to n, the recording strategy generation circuit will be complicated.

[0038] In response, measures are made to simplify the recording strategy generation circuit. Specifically, when n is an odd number and n≧5, the fall position of the first pulse is synchronized with either the rise or fall of the basic clock. For example, the fall of the first pulse may be positioned 2T away from the rise time of the logical data pulse (DATA pulse). Further, when n is an odd number and n≧7, the period from the fall of the first pulse till the fall of the second pulse is set to be longer than 2T but still in synchronization with the basic clock, the period typically being 2.5T. The periods of the rest of the pulses (from the third pulse and onward), except for the last period, are arranged to be 2T. The period from the fall of the second to last pulse (i=m-1) and the fall of the last pulse (i=m) is arranged to be ($2+\delta_1$o) T, where δ_1o is set to take a suitable value within a range of 0<δ_1o≦1, so as to minimize the mark deviation D(n). Thus, in the case where n is an odd number and n≧7, the multi-pulse sequence is suitably arranged by adjusting both the first and last pulses so that an overall consistency in the shape of the mark can be maintained in recording this mark, as opposed to adjusting only the last pulse in which case the consistency in the shape of the mark will be greatly sacrificed. In turn, the distortion of the waveform of the reproducing signal can be prevented and the jitter characteristics can be improved. Also, since the fall of the first pulse as well as the fall of the second pulse and the rest of the pulses except for the last pulse are all synchronized with either the rise or fall of the basic clock by setting the interval periods

to 2.5T or 2T, the design of the recording strategy generation circuit that generates the actual recording strategy can be simplified. Further, by optimizing the irradiation time of each pulse, the consistency in the shape of the mark can be maintained.

[0039] Additionally, in the case where n=5, the second pulse corresponds to the last pulse. Therefore, the period between the fall of the first pulse and the fall of the second pulse will be $(2+\delta_1 o)T$, where $0<\delta_1 o\leqq 1$.

[0040] When n is an even number and $n\geqq 4$, the fall of the first pulse is also synchronized with either the rise or fall of the basic clock. For example, the fall of the first pulse may be positioned 2T away from the rise time of the logical data pulse (DATA pulse). Further, when n is an even number and $n\geqq 6$, the periods of the second pulse and onward, except for the last pulse, are set to 2T so that the recording strategy generation circuit can be simplified. Also, the period between the fall of the second to last pulse (i=m-1) and the fall of the last pulse (i=m) is arranged to be $(2+\delta_1 e)$ T, where $\delta_1 e$ is set to a suitable value within a range of $0<\delta_1 e\leqq 1$, so that the mark deviation D(n) can be minimized. Since the fall of the first pulse as well as the fall of the second pulse and the rest of the pulses except for the last pulse are all synchronized with either the rise or fall of the basic clock by setting the pulse periods to 2T, the design of the recording strategy generation circuit that generates the actual strategy can be simplified. Further, by optimizing the irradiation time of each pulse, the consistency in the shape of the mark can be maintained.

[0041] When n is an even number, the mark deviation D(n) is smaller compared to when n is an odd number. Thus, the period between the fall of the second to last pulse (i=m-1) and the fall of the last pulse (i=m) may be set to 2T to further reduce the parameters used in the recording. That is, when n is an even number and $n\geqq 6$, the value $\delta_1 e$ is set to $\delta_1 e=0$ so that the periods of the pulses from the second pulse and onward, including the last pulse, all have uniform lengths of 2T. In this way, the circuit design can be further simplified and the consistency in the shape of the mark can be improved further.

[0042] Additionally, in the case where n=4, the second pulse corresponds to the last pulse. Therefore, the period between the fall of the first pulse and the fall of the second pulse will be $(2+\delta_1 o)T$, where $0<\delta_1 o\leqq 1$ and if $\delta_1 e=0$, this period will also be 2T.

[0043] In the present embodiment in which the mark length/mark space length modulation recording is performed, the mark space length is just as important as the mark length. In binary information, a mark and space are perceived as equals, and only the boundary between a mark and space is perceived as a point of significance. Normally, once the mark length is determined, the space length is automatically determined. However, in the present embodiment the space length is largely dependent upon the mark positioned before and after the space. That is, the space length of a space placed after a recording mark when n is an odd number and the space length of a space placed after a recording mark when n is an even number may have varying lengths. Thus, the space length needs to be controlled as well as the mark length according to the present embodiment.

[0044] To optimize both the mark length and the mark space length, the starting time T_{d1} of the rise of the first pulse, and the deviation time T_{d2} of the starting time of the rise of the pulse to P=Pe after the m^{th} off pulse with respect to the data termination time need to be controlled. Particularly, the deviation time T_{d2} exerts a significant influence on space jitters. This is because the deviation time T_{d2} is a parameter for determining the starting time of a space positioned after a recording mark. Thereby, this deviation time T_{d2} needs to be set to an optimum value according to each mark length.

[0045] However, for a recording mark in which $n\geqq 4$, the deviation time T_{d2} can be made to conform to a uniform time length. In this case, the deviation time T_{d2} is preferably set to $-1T\leqq T_{d2}\leqq +1T$. More specifically, the deviation time T_{d2} is optimally set to

$$-0.5T\leqq T_{d2}\leqq 0.75T.$$

[0046] On the other hand, the rise starting time T_{d1} also exerts an influence on space jitter. Since T_{d1} and T_{d2} are relative to each other, the range of T_{d1} when $n\geqq 4$ is preferably

$$0.0T\leqq T_{d2}\leqq +1.0T.$$

[0047] In the above description, ways of forming a plurality of parameters into one uniform parameter in determining the recording strategy have been described. However, for the 3T mark, which is the smallest mark, the parameters have to be set individually. This is because in the 3T mark m=1 and its pulse corresponds to the first as well as the last pulse. Thus, the strategy pattern for the 3T mark will clearly be different from the strategy patterns where $m\geqq 2$. In turn, the pulse irradiation time T_{on} (3, 1) needs to be set individually to T_{on} (3, 1)=T_{mp}'. The pulse irradiation time T_{mp}' is optimized according to the thermal characteristics and the optical characteristics of the recording layer material and also the scanning velocity and the basic clock period for the relevant recording. Further, the pulse irradiation time T_{mp}'

is preferably within a range of 0.5-2.0T. Similarly, times T_{d1} and T_{d2} also need to be set individually when n=3. In this case, T_{d1} is set to $T_{d13}=T_{d11}+\delta_2 T$, where δ_2 is preferably within a range of $0\leqq\delta_2\leqq1$ and the deviation time T_{d2} when n=3, denoted as T_{d2}', is preferably set to $-1T\leqq T_{d2}'\leqq 1T$.

[0048] As described above, in order to improve the consistency in the shape of the mark and the corresponding jitter, the recording power irradiation time of the last pulse $T_{on}(n, m)$ of the recording multi-pulse sequence and the recording power irradiation time of the other pulses $T_{on}(n, i)$ (i=1 through m-1) need to be optimized. However, it is known that the pulse irradiation times corresponding to the pulses other than the last pulse do not exert significant influences on the length of the recording mark. FIG.6 shows a relationship between the mark deviation and the pulse widths of the pulses other than the last pulse. As shown in this diagram, the dependency of the pulses on the mark deviation is quite small regardless of whether n is an odd number ($n_2=2m+1$) or an even number ($n_1=2m$), and there is no great difference between a case where n is even and a case where n is odd. Therefore, the recording strategy relating to the irradiation time $T_{on}(n, i)$ of the pulses other than the last pulse can be made to conform to a uniform recording strategy regardless of whether n is even or odd.

[0049] That is, when $1\leqq i\leqq m-1$, $m\geqq2$ (i.e. at least two pulses are used), and $n\geqq4$, all pulses can be made to conform to a uniform pulse width regardless of the values of n and i. Thus, the irradiation time $T_{on}(n, i)$ can be expressed by the following formula:

$$T_{on}(n, I)=T_{mp} \text{ (where } T_{mp} \text{ is a constant, } n\geqq4, \text{ and } 1\leqq i\leqq m-1)$$

In this case, it is preferable that the constant T_{mp} takes a value within in a range of 0.5-1.5T.

[0050] Further, when n is an even number, the influence of the last pulse on the recording mark is also quite insignificant. Thus, when n is even the irradiation time of the last pulse $T_{on}(n_1, m)$ may also be set to $T_{on}(n_1, m)=T_{mp}$ regardless of the value of n_1. Note that this arrangement also applies to the case when the EFM+ is used and n=14.

[0051] On the other hand, when n is an odd number, that is, when $n=n_2$, the pulse width of the last pulse can be made to conform to a uniform length regardless of the value of n_2 on condition that $m\geqq2$, namely, $n_2\geqq5$. This is because the mark deviation $D(n_2)$ is not greatly influenced by the pulse width of the last pulse and is substantially fixed regardless of the value of n_2. However, if a pulse width with a length equivalent to that for n_1 is set, the odd number marks will tend to be relatively shorter than the even number marks as shown in FIG.4. Thus, to cause the mark deviations for the n_1T mark and the n_2T mark to conform to a uniform deviation D_0, the irradiation time $T_{on}(n_2, m)$ of the last pulse for $n=n_2$ is made δ_3T longer than the irradiation time $T_{on}(n_1, m)=T_{mp}$ for $n=n_1$. Accordingly,

$$T_{on}(n_2, m)=T_{on}(n_1, m)+\delta_3 T$$

$$T_{1p}=T_{mp}+\delta_3 T$$

$$T_{on}(n_2, m)=T_{1p} \quad (n_2\geqq5,\ m\geqq2)$$

[0052] A suitable value for δ_3 is determined according to the thermal characteristics of the recording layer of the optical information recording medium. It is preferable that the value of δ_3 be within a range of 0-1.0; more specifically, within a range of 0-0.5. That is, when δ_3 is above 1.0, the length of the odd number mark will be too long. Also, when δ_3 is above 0.5, the effect of the change in the power Pw of the last pulse will be too strong and the dependency of the mark length on the recording power Pw will be very different from that when n is an even number, thereby significantly narrowing the recording power margin.

[0053] In this way, the irradiation time T_{on} of each of the pulses can be made to conform to a uniform length T_{mp} except for the last pulse when n is an odd number.

[0054] According to the above descriptions, the optimum recording strategy used in the information recording method of the present embodiment can be described with eight different parameters that are shown below:

T_{mp}
T_{mp}'
δ_{10}
δ_2
δ_3
T_{d1}

T_{d2}
T_{d2}'

[0055] This is a significant reduction compared to the conventional method in which 69 parameters are used in the EFM (8-14 modulation) of the CD and 77 parameters are used in the EFM+ of the DVD. Further, since the time T_{d1} is dependent upon the time T_{d2} and can therefore be regarded as a fixed value, the substantial number of parameters used to describe the recording strategy is seven.

[0056] Additionally, when the above recording strategy is implemented and the recording speed (scanning velocity) is changed, adjustments can be made by changing the irradiation times T_{mp}' and T_{mp} with respect to the scanning velocity v for the relevant recording. The other parameters can remain fixed with respect to the basic clock period T (v). That is, the parameters standardized by the basic clock period T(v), namely, $\delta_{1}o/T(v)$, $\delta_{2}/T(v)$, $\delta_{3}/T(v)$, $T_{d1}/T(v)$, $T_{d2}/T(v)$, and $T_{d2}'/T(v)$ are fixed regardless of the recording speed (scanning velocity).

[0057] The relationship between T(v) and v can be expressed by the formula $T(v)=L_0/v$ given that the line density is fixed (i.e. the amount of information assigned to a line of one unit length in the scanning direction is fixed). Herein, L_0 denotes the length corresponding to the basic clock period T on the optical information recording medium, generally referred to as the 'channel bit length'. In the case of a DVD, L_0=0.133 μm, and in the case of a CD, L_0=0.278 μm or L_0=0.324 μm. Thus, for example, when the scanning velocity doubles, the basic clock period T will be reduced to one-half (1/2).

[0058] When the scanning velocity increases as described above, it is preferable that the actual irradiation times $T_{mp}'(v)$ and $T_{mp}(v)$ decrease and the relative irradiation times $T_{mp}'(v)/T(v)$ and $T_{mp}(v)/T(v)$ increase. For example, given that $v=v_L$ and $v=v_H$ ($v_L<v_H$), the relative time with respect to the basic clock period T(v) will preferably be as follows:

$$T_{mp}(v_H)/T(v_H)>T_{mp}(v_L)/T(v_L)$$

$$T_{mp}'(v_H)/T(v_H)>T_{mp}'(v_L)/T(v_L)$$

[0059] However, the actual time will preferably be as follows:

$$T_{mp}(v_H)<T_{mp}(v_L)$$

$$T_{mp}'(v_H)<T_{mp}'(v_L)$$

[0060] This is described in further detail with reference to FIGS.7A and 7B. These drawings represent an exemplary case in which v_L=1.0, v_H=2.0, $T_{mp}(v_L)/T$=0.3, and $T_{mp}(v_H)/T$=0.5. In FIG.7A, the actual time is shown where $T_{mp}(v_H)<T_{mp}(v_L)$. However, in FIG.7B, the relative time is shown where the duties standardized by the respective basic clock periods $T(v_L)$ and $T(v_H)$ are: $T_{mp}(v_L)/T(v_L)$=0.3 and $T_{mp}(v_H)/T(v_H)$=0.5, so that $T_{mp}(v_H)/T(v_H)>T_{mp}(v_L)/T(v_L)$. Thus, the duties $T_{mp}(v)/T(v)$ and $T_{mp}'(v)/T(v)$ standardized by the basic clock period T(v) and the actual irradiation times $T_{mp}(v)$ and $T_{mp}(v)$ have inverse relationships with respect to a change in the scanning velocity (i.e. the duties increase and the actual times decrease when the scanning velocity increases and vice versa).

[0061] Also, the irradiation times T_{mp} and T_{mp}' are preferably expressed by a function that is proportional to a function of the scanning velocity v: $\alpha=v/v_0$. More specifically, the irradiation times T_{mp} and T_{mp}' are preferably expressed by a function $T_{mp}(\alpha)/T(\alpha)=a\times\alpha+b$. Herein, v_0 denotes the minimum scanning velocity at which recording is possible in an optical information recording medium, α denotes a real number greater than or equal to 1. The range of α represents the range of the scanning velocity at which recording is possible in the optical information recording medium. For example, in the case of a disk type recording medium with a diameter of 120 mm that uses the CAV (Constant Angular Velocity) method, the above range is preferably set to $1\leqq\alpha\leqq2.4$; more specifically, $1\leqq\alpha\leqq4$.

[0062] FIG.8 shows the functions that change the duty of the irradiation time in response to a change in the scanning velocity. In the case of a CD-RW, wherein L_0=278 nm and the scanning velocity v=9.6 m/s-38.4 m/s=8x-32x (v_0=9.6 m/s=8x, α =1-4), which is particularly pertinent to the present embodiment, it is preferable that $0.14\leqq a\leqq0.29$ and $0.2\leqq b\leqq0.4$. In this diagram, the characteristics of a duty T_{mp}/T of a CD-RW with a scanning velocity of 1x-4x (v_0=1.2 m/s, α=1-4) and the characteristics of a duty T_{mp}/T of a HS CD-RW with a scanning velocity of 4x-10x (v_0=4.8 m/s, α=1-2.5) are also shown. Additionally, although not shown, in the case of a DVD+RW, v_0=3.49 m/s, and α=1-2.4.

[0063] The constants a and b can be set according to the characteristics of the optical information recording medium; however, the constants are preferably set to:

$$0.1 \leqq a \leqq 0.4$$

$$0.1 \leqq b \leqq 0.4$$

By setting the constants according to the above restrictions, the present embodiment can be arranged to be compatible with the recording strategies conceived for α=1 through 4.

[0064] The irradiation time T_{mp}' when n=3 also changes according to α. Thus, based on the above function, the value calculated from the formula shown below can be used:

$$T_{mp}'(\alpha)=(T_{mp}(\alpha)/T_{mp}(1))\times T_{mp}' \quad (1)$$

[0065] Thus, according the information recording method of the present embodiment, the power Pw does not change significantly even when α is changed since the pulse irradiation time T_{mp} is made relatively shorter with respect to the basic clock period. Thereby, this method is suitable for use in CAV recording, or Z-CLV (Zone-Constant Linear Velocity) recording in which CLV recording is performed for each radial range so that pseudo-CAV recording is realized (when the radial range takes the limiting value of 0, the Z-CLV recording corresponds to the CAV recording).

(Pre-formatting on the Optical Information Recording Medium)

[0066] As described above, it is possible to determine a recording method according to a complex recording strategy using a limited number of parameters. By pre-formatting the information corresponding to these parameters, the information recording apparatus is able to read the information of the parameters from the relevant optical information recording medium so as to establish highly accurate recording conditions.

[0067] One of the primary features of the present embodiment is that the parameter information is preformatted on the optical information recording medium.

[0068] The above pre-formatting can be performed according to any type of pre-formatting method. The various methods of pre-formatting are: the pre-pit method, the wobble encoding method, and the formatting method. The pre-pit method is a method of pre-formatting information concerning the recording conditions using a ROM pit in any given area of the optical information recording medium. This method is advantageous in that high productivity can be realized since the ROM pit is formed along with the formation of the substrate, and also, high reproducing reliability and large information capacity can be provided. However, there are still many problems that need to be solved concerning the technology for forming a ROM pit (i.e. hybrid technology) and the pre-formatting technology using a RW pre-pit is still considered to be quite difficult.

[0069] The formatting method is a method of recording information using the same method for normal recording in the optical information recording apparatus. However, with this method, information has to be formatted onto each optical information recording medium after its fabrication, thereby lowering productivity. Further, since the information formatted according to this method will be re-writable, this method is not suitable for recording characteristic information of the recording medium.

[0070] The wobble encoding method is the method that is actually used in the pre-formatting of the CD-RW and the DVD+RW. This method uses a technology of encoding address information of the optical information recording medium in a grove (guiding trench in the recording medium) wobble. The encoding method may be a frequency modulation used for the ATIP (Absolute Time in Pregroove) in a CD-RW or a phase modulation used in the DVD+RW. In the wobble encoding method, the groove wobble is formed on a substrate of the optical information recording medium along with the address information upon the formation of the substrate, this leading to increased productivity. Also, unlike the prepit method wherea special ROM pit has to be formed, the wobble encoding method does not require such special measure, thereby facilitating the formation of the substrate.

[0071] In the following, the above described pre-formatting method of the parameters relating to the recording strategy performed in the CD-RW will be described. FIGS.9 and 10 show an exemplary format of each of the areas of an optical information recoding medium 1 according to the CD-RW standard. In the groove formed area of the disk-shaped optical information recording medium 1, an inner-perimeter unused area 2, a test recording area 3, a lead-in area 4, an information recording area 5, a lead-out area 6, and an outer-perimeter unused area 7 are assigned.

[0072] In the optical information recording medium 1 (CD-RW) having the above configuration, the media information (parameter information) that is to be pre-formatted on the recording medium is in the form of ATIP (Absolute Time In Pregroove) Extra Information. ATIP is the address information pre-formatted on the CD-RW disk. Owing to the fact

that the CD started out as a sound information recording medium, its address information is represented as time information, that is, the information is represented as M:S:F. Herein M stands for minutes, and the value of M is within a range of 00-99. S stands for seconds, and its value is within a range of 00-59. F stands for frames, and its value is within a range of 00-74. Also, note that 1M=60S, and 1S=75F. Information of eight bits is assigned to each of M, S, and F, thereby information of one ATIP frame will be 24 bits. Although each of M, S, and F may potentially have a value within a range of 0-255, the values that are actually used are within the ranges mentioned above. Thus, the unused bits can be used to format additional information other than address information. The ATIP Extra Information preformatting method is a method that uses the above unused bits to pre-format additional information.

[0073] In FIG.11, a data format of one ATIP frame, which consists of 42 bits, is shown. The first four bits of the ATIP frame are called the synchronization portion, which indicates the beginning of the frame. Upon reproducing the ATIP, the information recording apparatus recognizes this synchronization portion as the beginning of the frame. Therefore, the synchronization portion is made of a special pattern called the synchronization pattern. The 24 bits from the 5^{th} to 28^{th} bits following the synchronization portion are the address information portion. The 24 bits are further divided into three 8-bit portions. The portions M1-M8 represent the address information of M (i.e. minutes), the portions S1-S8 represent the address information of S (i.e. seconds), and the portions F1-F8 represent the address information of F (i.e. frames). The 14 bits from the 29^{th} bit to the 42^{nd} bit following the address information portion are the so-called 'CIRC remainder' portion, which corresponds to error correction codes using the CIRC (cross-interleaved Reed Solomon code).

[0074] According to the CD-RW standard, the address information portion content is divided into seven types depending on the respective values of M1, S1, and F1, as shown below and in FIG.11:

(M1, S1, F1)=(0, 0, 0) or (1, 0, 0): Normal Address
(M1, S1, F1)=(1, 0, 1): Special Information 1
(M1, S1, F1)=(1, 1, 0): Special Information 2
(M1, S1, F1)=(1, 1, 1): Special Information 3
(M1, S1, F1)=(0, 0, 1): Additional Information 1
(M1, S1, F1)=(0, 1, 0): Additional Information 2
(M1, S1, F1)=(0, 1, 1): Additional Information 3

[0075] Herein, information other than the 'normal address' correspond to the ATIP Extra Information. This ATIP Extra Information contains characteristic information of the disk such as the type of disk, and recording conditions (i.e. recording power, parameters for setting the optimum recording power, parameters for determining the recording strategy, etc.) of the disk.

[0076] The ATIP Extra Information is placed at the lead-in area 4 of the optical information recording medium 1, preceded by nine consecutive frames of the normal address information. That is, to reproduce the six types of ATIP Extra Information, at least 60 frames of the lead-in area 4 need to be reproduced.

[0077] In the following, the pre-formatting of the parameters for determining the recording strategy on the optical information recoding medium 1 using the eight types of parameters, T_{d1}/T, T_{d2}/T, T_{d2}'/T, T_{mp}/T. T_{mp}'/T, $\delta_1 o$, δ_2, and δ_3, standardized by the basic clock period T, in accordance with the information recording method of the present embodiment will be contemplated. It is assumed that the parameter information corresponds to Additional Information 1 and Additional Information 2 of the ATIP Extra Information.

[0078] The Additional Information 1 has fixed values for M1, S1, and F1, which are set to 0, 0, 1, respectively, and the Additional Information 2 has fixed values for M1, S1, and F1, which are set to 0, 1, 0, respectively. Thereby, the address information portion will have states as shown in FIG.12. In turn, each of the other bits is assigned to represent the following parameters:

Additional Information 1

[0079]

(M2, M3, M4): T_{d1}/T
(M5, M6, M7) : T_{d2}/T
(M8, S2, S3) : T_{d2}'/T
(S4, S5, S6) : T_{mp}/T
(S7, S8, F2) : T_{mp}'/T
(F3, F4, F5) : $\delta_1 o$
(F6, F7, F8) : δ_2

Additional Information 2

[0080]

(M2, M3, M4) : δ_3

[0081] In this example, information worth three bits is assigned to each parameter. That is, information of eight levels is assigned to each parameter. The conversion of each of the bits into a parameter value (real number) is performed by referring to a conversion table. FIGS.14-21 show exemplary conversion tables 11a-11h showing the relationship between each of the parameters and its corresponding bits.

[0082] For example, it is assumed in the following description that optimum recording characteristics can be realized in a given optical information recording medium 1 with the parameter values shown below:

$T_{d1}/T=0.50$
$T_{d2}/T=0.00$
$T_{d2}'/T=0.25$
$T_{mp}/T=1.00$
$T_{mp}'/T=1.06$
$\delta_{1}o=0.38$
$\delta_2=0.25$
$\delta_3=0.28$

[0083] Accordingly, the corresponding bit number of each bit obtained based on the tables 11a-11h shown in FIGS. 14-21 will be as follows:

Additional Information 1

[0084]

(M2, M3, M4)=(0, 1, 1)
(M5, M6, M7)=(1, 0, 0)
(M8, S2, S3)=(1, 0, 1)
(S4, S5, S6)=(1, 0, 0)
(S7, S8, F2)=(1, 0, 1)
(F3, F4, F5)=(0, 1, 0)
(F6, F7, F8)=(0, 0, 1)

Additional Information 2

[0085]

(M2, M3, M4)=(1, 0, 0)

In FIG.13, the bit information of each of the parameters pre-formatted in the Additional Information 1 and the Additional Information 2 according to the above example is shown. (Herein, X represents undefined information and can therefore take any value.)

[0086] When the optimum values for the parameters relating to the determination of the recording strategy are different from the above due to a difference in physical properties in the recording layer and the like, the corresponding bit information for the changed parameters can be pre-formatted to the Additional Information 1 and Additional Information 2 using the conversion tables 11a-11h.

[0087] According to the wobble encoding method, the absolute information capacity tends to be lower than that realized by the other pre-formatting methods. Normally, the wobble frequency is within a frequency band that will not cause mutual interference with the frequency of the recording information. That is, a frequency below 1/30, and preferably below 1/100 of the frequency of the recording information. The information density decreases even further when frequency modulation is performed. Also, the information density decreases when the redundancy in the address information is used as in the ATIP Extra Information pre-formatting for the CD-RW.

[0088] When there is a shortage of information capacity, a new area can be created. In the case of a CD-RW, the ATIP Extra Information is normally encoded in the lead-in area 4. However, when this area alone cannot hold all the

information, the ATIP Extra Information may be encoded in the inner-perimeter unused area 2 or the outer-perimeter unused area 7 of the disk. Examples of the unused areas 2 and 7 are the areas of the disk situated closer to the inner circumference than the PCA (Power Calibration Area= test recording area 3) and the areas of the disk situated closer to the outer circumference than the lead-out area 6.

[0089] Also, as described above, the encoding of the parameter may involve encoding a binary number converted from a real number or encoding information converted by a conversion table. However, in either case, means for decoding the information encoded on the medium to appropriately set the recording strategy need to be provided in the information recording apparatus..

(Recording Strategy Generation Method)

[0090] An information recording apparatus compatible with a CD-RW as the optical information recording medium 1 reproduces the ATIP Extra Information upon executing a recording operation on this optical information recording medium 1 (including the mounting of the medium). The above recording apparatus compatible with the optical information recording medium 1 (CD-RW) has to be able to reproduce the Additional Information 1 and also needs to have the conversion tables for converting the bits of the Additional Information 1 into real numbers. The information recording apparatus reproduces the Additional Information 1 and the Additional Information 2 and acquires the values of each bit from the optical information recording medium 1. Then the information recording apparatus obtains the parameter values from the above bit information using the conversion tables 11a-11h, and determines the optimum recording strategy based on the real numbers of the above parameters. According to this method, the information recording apparatus is able to determine an optimum recording strategy for each optical information recording medium. Thereby when an optical information recording medium 1 with a different optimum recording strategy is used, that is, when the optical information recording medium 1 has different parameter values, the bit information corresponding to the parameters for determining the optimum recording strategies for this particular optical information recording medium 1 is preformatted in the Additional Information 1 and the Additional Information 2, and the information recording apparatus is able to set an optimum recording strategy for this optical information recording medium 1.

[0091] FIG.22 shows a summary flowchart of the processing procedures of the above recording strategy generation method. These processes are executed by a system controller (to be described later) of the information recording apparatus, for example.

[0092] First of all, before initiating the recording operation, the preformatted information is reproduced from the optical information recording medium 1 that is mounted on the recording apparatus (step S1). In other words, this process involves accessing the addresses in which the parameters relating to the determination of the recording strategy, namely, T_{d1}/T, T_{d2}/T, T_{d2}'/T, T_{mp}/T. T_{mp}'/T, $\delta_1 o$, δ_2, and δ_3, are recorded and reproducing the preformatted information. Then, the reproduced preformatted information (bit information of the parameters T_{d1}/T, T_{d2}/T, T_{d2}'/T, T_{mp}/T. T_{mp}'/T, $\delta_1 o$, δ_2, and δ_3) are decoded (step S2). That is, each item of the parameter information is converted from bit information to real number information using the conversion tables 11a-11h. Then, the optimum recording strategy is generated and set by referring to the real number information of the converted parameters T_{d1}/T, T_{d2}/T, T_{d2}'/T, T_{mp}/T. T_{mp}'/T, $\delta_1 o$, δ_2, and δ_3, so that an optimum multi-pulse sequence pattern can be created (step S3). After this step, a process of setting the optimum recording power is performed on the appropriate occasion (step S4). This corresponds to the process of performing test writing using the determined optimum recording strategy to verify the suitability of the strategy and to determine the optimum recording power. An example of the test writing process is the OPC (Optimum Power Control) used in the CD-R/RW and the DVD+RW/R. In the recording operation, the recording power determined according to the above mentioned procedures is used to perform recording based on a predetermined recording strategy (step S5).

(Information Recording Apparatus)

[0093] FIG.23 shows an exemplary configuration of the information recording apparatus used in order to realize the information recording method based on the above recording strategy.

[0094] The information recording apparatus has a rotation control structure 22 that includes a spindle motor 21 that rotates the optical information recording medium 1, and an optical head 24 that has an objective lens that irradiates and condenses a laser beam on the optical information recording medium 1 and a laser light source such as a semiconductor laser diode LD 23, wherein the optical head 24 is arranged to be movable along the disk radius direction to seek an address. An actuator control structure 25 is connected to an objective lens drive and a power range system of the optical head 24. A wobble detection unit 27 that includes a programmable BPF 26 is connected to this actuator control structure 25. An address demodulation circuit 28 that demodulates address information from a detected wobble signal is connected to this wobble detection unit 27. A recording clock generation unit 30 that includes a PLL synthesizer circuit 29 is connected to this address demodulation circuit 28. A drive controller 31 functioning as speed controlling

means is connected to the PLL synthesizer circuit 29.

[0095] The drive controller 31, which is connected to a system controller 32, is also connected to the rotation control structure 22, the actuator control structure 25, the wobble detection unit 27, and the address demodulation circuit 28.

[0096] Further, the system controller 32 has a so-called Micom structure that implements a CPU and the like. This system controller 32 has a ROM 33 that contains the above described conversion tables 11a-11h. Also, an EFM encoder 34, a mark length counter 35, and a pulse number control unit 36 are connected to the system controller 32. Further, a recording pulse sequence control unit 37 that functions as light emission waveform control means is connected to the EFM encoder 34, the mark length counter 35, the pulse number control unit 36, and the system controller 32. This recording pulse sequence control unit 37 includes a multi-pulse generation unit 38 that generates a multi-pulse (on pulse, off pulse) sequence designated by the recording strategy, an edge selector 39, and a pulse edge generation unit 40.

[0097] Also, a LD drive unit 42 is connected to the output side of this recording pulse sequence control unit 37. The LD drive unit 42 functions as light source driving means that activates the semiconductor laser diode LD 23 in the optical head 24 by switching a driving electric current source 41 corresponding to each of the recording power Pw, the erasing power Pe, and the bias power Pb.

[0098] In the following, the procedures for realizing a recording process on the optical information recording medium 1 using the information recording apparatus having the above described configuration will be described.

[0099] First, the rotation control structure 22 controls the rotation (number of rotations) of the spindle motor 21 so that the recording line speed corresponds to the desired recording speed, this being done under the control of the drive controller 31. Then, an address is demodulated from a wobble signal detected and separated from a push-pull signal obtained from the optical head 24 by means of the programmable BPF 26, and at the same time, a recording channel clock is generated by the PLL synthesizer circuit 29. Next, the recording channel clock and EFM data that contains recording information are input to the recording pulse sequence control unit 37. Then a multi-pulse sequence in accordance with a recording strategy shown in FIG.4, for example, is generated by means of the multi-pulse generation unit 38 in the recording pulse sequence control unit 37. Then, at the LD drive unit 42, each driving electric current source 41 for setting the irradiation power to Pw, Pe, and Pb, respectively is switched on so that a LD light emission waveform that corresponds to a recording pulse sequence is generated. In turn, the recording pulse sequence is generated at the semiconductor laser diode LD 23.

[0100] Note that according to the present embodiment, a multi-level pulse edge generation unit 40 that has a resolution that is 1/20 of the recording channel clock period is implemented in the recording pulse sequence control unit 37, wherein the generated edge pulses are input to an edge selector (multiplexer) 39 after which an edge pulse is selected by the system controller 32 according to the parameter T_{d1} so that a first pulse rise control signal and the like are generated. A multi-level delay circuit for the pulse edge generation unit 40 may be composed of a gate delay element with a high resolution or a ring oscillator and a PLL circuit.

[0101] Using the above first pulse rise control signal as a basis, a multi-pulse sequence that is in synchronization with the basic clock period T is generated based on the parameters such as T_{mp}, T_{mp}', δ_1o, δ_2, and δ_3. Similarly, with respect to the last off pulse irradiation time $T_{off}(n, m)$, a last off pulse rise control signal is generated by the edge pulse selected by the system controller 32 based on the parameter T_{d2} or T_{d2}'.

[0102] Also, in a recording pulse sequence control unit 37 according to the present embodiment, the mark length counter 35 for measuring the mark length of the EFM signal obtained from the EFM encoder 34 is provided. Herein a multi-pulse sequence is generated via the pulse number control unit 36 so that one set of pulses (on pulse with the power Pw and off pulse with the power Pb) is generated for every increase of 2T in the mark counter value. This operation is made possible by selecting the rear (or trailing) edge of the first pulse with the edge selector 39 after which the front (or leading) edge of the subsequent multi-pulse sequence is selected by the edge pulse generated from the next recording channel clock period, followed by the selection of the rear edge by the pulse edge generated from the next recording channel clock period.

[0103] Alternatively, the multi-pulse generation unit may have a configuration in which a recording frequency division clock that divides the recording channel clock into two is generated, from which an edge pulse is generated using a multi-level delay circuit, and one set of pulses (on pulse with the power Pw and off pulse with the power Pb) is generated for every increase of 2T in the recording channel clock by selecting the front and rear edges with the edge selector. In this configuration, the substantial operation frequency of the multi-pulse generation unit will be reduced to 1/2, thereby realizing an even higher recording speed.

(Modification)

[0104] In the above description of the preferred embodiments, the application of the present invention in a phase change type optical information recording medium is described. However, the present invention is also applicable in the so-called dye optical information recording medium that can be written only once such as the CD-R or DVD-R. In

such case, the irradiation powers Pe and Pb are substantially equal (Pe≒Pb) and a bilevel pulse irradiation pattern will be realized wherein the irradiation power Pb is irradiated between the pulses $P_{on}(n, i)$ and $P_{on}(n, i+1)$ that are irradiated with the power Pw as shown in FIG.24.

[0105] In the following, specific examples in accordance with the above descriptions of the present invention are given.

(Example 1)

[0106] A lower dielectric layer, a recording layer, an upper dielectric layer, and a reflection layer are successively formed on a polycarbonate CD-RW substrate using the spattering method. A dielectric material made of ZnS with 20 mol% SiO_2 is used as the lower dielectric layer material and the upper dielectric layer material, and an AgInSbTe alloy with a very small amount of Ge added thereto is used as the recording layer material. Ag is used for the reflection layer material. The film thickness of each of the layers is: 70 nm for the lower dielectric layer, 15 nm for the recording layer, 20 nm for the upper dielectric layer, and 140 nm for the reflection layer. Further, a resin protective layer is formed on top of the above structure using a spin coating method. This protective layer is then hardened through irradiation of ultraviolet light. An ultraviolet activated resin, which is a protective layer material for a CD that is on the market, is used as the protective layer material. The film thickness of the resin protective layer is approximately 10 μm.

[0107] Right after the formation of the film layers, the recording layer is in a rapid cooling state and is thereby in an amorphous state. Thus, the CD-RW is initialized using a CD-RW initialization apparatus so as to crystallize the entire surface of the disk. The initialization is realized by irradiating and scanning high energy laser throughout the entire surface of the disk. The initialization laser has a wavelength of 830 nm and its beam diameter is 1 μm in the scanning direction and 80 μm in the direction perpendicular to the scanning direction. The irradiation intensity is 800 mW (power consumption) and the scanning velocity is 2.5 m/s. The disk produced according to the above specifications satisfies the standards of the CD-RW disk in an unrecorded state.

[0108] A recording experiment in which recording equivalent to a 24× speed recording on a CD is performed in the above disk. In this experiment, a DDU-1000 by Pulstec Industrial Co., Ltd. is used as the information recording/reproducing apparatus, and an AWG 610 (Arbitrary Waveform Generator) by Sony/Tektronix Corporation is used as a recording strategy generation apparatus. The resulting recording strategy patterns have configurations identical to those shown in FIG.4 and the parameters are set as follows:

T=9.6 ns
$T_{mp}/T=1.125$
$T_{mp}'/T=1.563$
$\delta_1 o=0.30$
$\delta_2=0.30$
$\delta_3=0.125$
$T_{d1}/T=0.50$
$T_{d2}/T=0.05$
$T_{d2}'/T=0.10$

[0109] When the 24× speed recording is performed using the recording strategy according to the above parameters, the following recording conditions are obtained:

Pw=32 mW
Pe=11 mW
v=28.8 m/s
DOW count=1-1000

(DOW: Direct Over Write, a rewrite that is not accompanied by an erasing operation; the rewrite can be performed at least 1000 times according to the CD-RW standard)

[0110] Table 1 shown below shows the results from measuring the 3T mark jitter and the 3T mark space jitter at a normal speed (v=1.2 m/s) after the recording.

Table 1

DOW Count	3T Mark Jitter (ns)	3T Space Jitter (ns)
0	16	20

Table 1 (continued)

DOW Count	3T Mark Jitter (ns)	3T Space Jitter (ns)
1	27	31
10	24	28
1000	28	33

[0111] According to the results shown in table 1, it can be determined that the disk on which the experiment is performed satisfies the CD-RW standard which sets a condition for the jitter to be less than 35 ns (jitter<35 ns) when the DOW is performed 1000 times or less.

(Example 2)

[0112] Recording equivalent to an 8× speed recording on a CD is performed on the CD-RW disk of Example 1. As for the recording strategy, only the parameters T_{mp}/T and T_{mp}'/T are changed to:

$T_{mp}/T=0.500$ (4/9 of Example 1)
$T_{mp}'/T=0.695$ (4/9 of Example 1)
$T=28.9$ ns

The values for the rest of the parameters, δ_1o, δ_2, δ_3, T_{d1}/T, T_{d2}/T, and T_{d2}'/T are arranged to have the same values as Example 1.

[0113] Consequently, the recording conditions will be as follows:

Pw=30 mW
Pe=9 mW
v=9.6 m/s
DOW count=1-1000 times

[0114] Table 2 (shown below) shows the results from measuring the 3T mark jitter and the 3T mark space jitter at normal speed after the recording.

Table 2

DOW Count	3T Mark Jitter (ns)	3T Space Jitter (ns)
0	15	17
1	25	28
10	22	25
1000	24	28

[0115] From the results shown in the above table 2, it can be determined that the 8× speed recording is realized by simply reducing the irradiation time T_{mp} and T_{mp}' to 4/9 of that in Example 1. Also, the jitter is below 35 ns even when the DOW count reaches 1000 times, meaning good characteristics are realized.

(Example 3)

[0116] Taking the Embodiments 1 and 2 into consideration, the information recording apparatus will be able to determine the optimum recording strategy by pre-formatting the parameter information shown below on the optical information recording medium 1.

$\delta_1o=0.30$
$\delta_2=0.30$
$\delta_3=0.125$
$T_{d1}/T=0.50$
$T_{d2}/T=0.05$

$T_{d2}'/T=0.10$
a=3.125
b=0.188
α=3

[0117] In the following, the various advantages of the present invention will be described.

[0118] First, according to the present invention, a recording strategy is used to form a recording mark with a multi-pulse sequence, which is increased by one pulse with an irradiation power Pw for every increase of 2T in the temporal length nT. Thus, the irradiation time per pulse can be made longer with respect to the basic clock period T, which in turn can reduce the influence from the time required for the rise of the pulse light. Also, a high modulation rate at a low recording power can be realized and jitter can be reduced. Particularly, when n is an odd number and $n \geqq 7$, a period from the fall of the first pulse to the fall of a second pulse in the multi-pulse sequence is arranged to be greater than 2T, and a period corresponding to the last pulse is set to $(2+\delta_1 o)T$ where the value of $\delta_1 o$ is optimized within the range of $0<\delta_1 o \leqq 1$. Thus, the multi-pulse sequence is adjusted from both the front pulse side and the rear pulse side so that an overall consistency can be maintained in the mark shape upon recording the mark, whereas, in a case where the multi-pulse is adjusted only from the rear pulse side, the consistency of the mark shape can be severely degraded. Accordingly, a distortion in the waveform of the reproducing signal can be prevented and the jitter characteristic can be improved. Also, when $n \geqq 4$, the fall of the first pulse is synchronized with a basic clock, and the fall of the second pulse and the rest of the pulses except for the last pulse are also synchronized with the basic clock by irradiating the pulses at periods of 2.5T or 2T. In this way, the design of a recording strategy generation circuit that generates the actual recording strategy can be simplified.

[0119] Further, the period from the fall of the first pulse to the fall of the second pulse when n is an odd number and $n \geqq 7$ may typically be set to 2T.

[0120] Whether n is odd or even, parameters that have little influence on the recording characteristics are made to conform to a uniform parameter so that the optimum recording strategy can be accurately determined with few parameters.

[0121] Also, when n is an even number and $n \geqq 6$, the periods of the pulses other than the first pulse may all be set to 2T so that the parameters for determining the recording strategy can be reduced even further.

[0122] Further, by adjusting the parameters T_{d1} and δ_2 according to each optical information recording medium and determining the end of a space preceding a recording mark, the actual length of the mark and space and the transition area from space to mark can be optimized and jitter can be reduced.

[0123] The present invention is applicable to a dye type WORM (write once, read many) optical information recording medium, where two power levels are used in the recording.

[0124] Also, the present invention is applicable to a rewritable optical information recording medium made of a phase change recording material, where three power levels are used in the recording. In this case, a direct over write is made possible.

[0125] Additionally, by adjusting the parameters T_{d2} and T_{d2}' according to each optical information recording medium, the actual length of the mark and the space following the mark can be optimized and jitter can be reduced.

[0126] Also, by conforming the irradiation times of all the pulses, except for the pulse when n=3 and the last pulses when n is an odd number, to a uniform value, the parameters that have little influence on the recording characteristics are reduced so that the parameters for determining the optimum strategy can be reduced even further.

[0127] By fixing the parameters T_{1p} and T_{mp} regardless of the optical information recording apparatus, the parameters that have little influence on the recording characteristics are reduced so that the recording strategy generation circuit can be simplified.

[0128] Further, by changing only the duties T_{mp}/T of the irradiation time of the pulses in response to a change in the scanning velocity of the recording, the recording strategy can be used for varying scanning velocities. Thereby, recording is possible in a wide range of scanning velocities using few parameters where jitter characteristics are improved. Particularly, by making the irradiation time T_{mp} of a pulse with respect to the basic clock T relatively shorter with the decrease of the scanning velocity, the intensity of the power Pw does not have to be changed even when the scanning velocity is changed so that the recording strategy can be compatible with different scanning velocities.

[0129] Additionally, by arranging the irradiation time T_{mp} to be in accordance with a function of α, the parameters for realizing the above information recording can be further optimized.

[0130] Also, by setting the irradiation time when n=3 to $T_{mp}'(v_H)/T_{mp}'(v_L)=T_{mp}(v_H)/T_{mp}(v_L)$, the irradiation time when n=3 is made to conform with the irradiation time when $n \geqq 4$ with respect to the actual time. This measure is effective in reducing the parameters relating to the recording strategy.

[0131] Further, by fixing the parameters except for T_{mp} and T_{mp}' regardless of the scanning velocity, the recording strategy does not have to be changed even when the scanning velocity in the recording is changed. Thus, recording is possible over a wide range of scanning velocities using few parameters where jitter is improved.

[0132] Also, by pre-formatting the information of $\delta_1 o$ as parameter information relating to the recording strategy for determining the time $T_1 o$ from the fall of the second to last pulse to the fall of the last pulse on the optical information recording apparatus, the information recording apparatus will be able to set a recording strategy that satisfies the optimum recording conditions with ease.

[0133] The present application is based on and claims the benefit of the earlier filing dates of Japanese priority application No.2002-136177 filed on May 10, 2002 and Japanese priority application No.2002-266501 filed on September 12, 2002, the entire contents of which are hereby incorporated by reference.

Claims

1. An information recording method for recording information on an optical information recording medium according to a mark length recording scheme in which a temporal length of a recording mark is represented as nT where n denotes a natural number and T denotes a basic clock period, wherein:

   the recording mark. is formed by a multi-pulse sequence, which is increased by one pulse with an irradiation power Pw for every increase of 2T in the temporal length nT; and
   a recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that:

      when $n \geqq 4$, the fall of a first pulse of the multi-pulse sequence is synchronized with the basic clock; and
      when n is an odd number and $n \geqq 7$, a period from the fall of the first pulse to the fall of a second pulse in the multi-pulse sequence is arranged to be greater than 2T and in synchronization with the basic clock, periods of pulses after the second pulse except for a last pulse of the multi-pulse sequence are arranged to be 2T, and a period from the fall of a second to last pulse to the fall of the last pulse, denoted as $T_1 o$, is set to $T_1 o=(2+\delta_1 o)T$ where $0<\delta_1 o \leqq 1$.

2. The information recording method as claimed in claim 1, wherein:

   the period from the fall of the first pulse to the fall of the second pulse when n is an odd number and $n \geqq 7$ is arranged to be 2.5T.

3. The information recording method as claimed in claim 1, wherein:

   the recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that when n is an even number and $n \geqq 6$, periods of the pulses after the first pulse of the multi-pulse sequence are set to be 2T, and the period from the fall of the second to last pulse to the fall of the last pulse, denoted as $T_1 e$, is set to $T_1 e=(2+\delta_1 e)T$ where $0<\delta_1 e \leqq 1$.

4. The information recording method as claimed in claim 3, wherein $\delta_1 e$ is set to $\delta_1 e=0$.

5. The information recording method as claimed in claim 1, wherein:

   the recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that when a time from the rise of a logical data pulse to the rise of the first pulse of the multi-pulse sequence when $n \geqq 4$ is denoted as T_{d1} and a time from the rise of a logical data pulse to the rise of the first pulse of the multi-pulse sequence when n=3 is denoted as T_{d13}, $T_{d13}= T_{d1}+ \delta_2 T$ where $0< \delta_2 \leqq 1$.

6. The information recording method as claimed in claim 1, wherein:

   light with an irradiation power Pb is irradiated in between the pulses with the irradiation power Pw in the multi-pulse sequence where Pw>Pb.

7. The information recording method as claimed in claim 6, wherein:

   light with an irradiation power Pe is irradiated to record a mark space where Pw>Pe>Pb.

8. The information recording method as claimed in claim 7, wherein:

the recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that:

a last off pulse with the irradiation power Pb is added after the irradiation of the last pulse with the irradiation power Pw in the multi-pulse sequence;
a pulse with the irradiation power Pe is added after the last off pulse with the irradiation power Pb; and
an interval between the rise of the pulse with the irradiation power Pe and the fall of a logical data pulse when $n \geqq 4$ is set to T_{d2} where $-1T \leqq T_{d2} \leqq 1T$, and an interval between the rise of the pulse with the irradiation power Pe and the fall of a logical data pulse when n=3 is set to T_{d2}' where $-1T \leqq T_{d2}' \leqq 1T$.

9. The information recording method as claimed in claim 8, wherein:

the recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that:

when an irradiation time of the irradiation power Pw of an m^{th} pulse (where m is a natural number), which corresponds to the last pulse of the multi-pulse sequence, is denoted as $T_{on}(n, m)$, and an irradiation time of the irradiation power Pw of a pulse other than the m^{th} pulse is denoted as $T_{on}(n, i)$ where i is a value within a range of 1 through m-1, all the irradiation times $T_{on}(n, i)$ of the multi-pulse sequence, other than the irradiation time when n=3 and the irradiation time of the last pulse when n is an odd number and $n \geqq 5$, are set equal to $T_{on}(n, i)=T_{mp}$ where T_{mp} is a constant and $0.5T \leqq T_{mp} \leqq 1.5T$; and
the irradiation time of the last pulse when n is an odd number and $n \geqq 5$, denoted as $T_{on}(n, m)=T_{1p}$, is set to $T_{1p}=T_{mp}+\delta_3 T$ where $0 \leqq \delta_3 \leqq 1$.

10. The information recording method as claimed in claim 9, wherein the recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that T_{1p} and T_{mp} are arranged to be fixed values regardless of the optical information recording medium.

11. The information recording method as claimed in claim 9, wherein:

the recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that:

when differing scanning velocities $v=v_L$ and $v=v_H$ are used in the recording where $v_L < v_H$, the basic clock periods T corresponding to the scanning velocities v_L and v_H are denoted as $T(v_L)$ and $T(v_H)$, respectively, a line density is fixed to obtain a relationship $v_L \times T(v_L)=v_H \times T(v_H)$, the irradiation time T_{mp} upon recording at the scanning velocity v_L is denoted as $T_{mp}(v_L)$, and the irradiation time T_{mp} upon recording at the scanning velocity v_H is denoted as $T_{mp}(v_H)$, the relationships between the irradiation times corresponding to the differing scanning velocities v_L and v_H satisfy conditions $T_{mp}(v_H) < T_{mp}(v_L)$ and $T_{mp}(v_H)/T(v_H) > T_{mp}(v_L)/T(v_L)$.

12. The information recording method as claimed in claim 11, wherein:

the recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that:

when a minimum scanning velocity for the recording is denoted as v_0, a basic clock period corresponding to the minimum scanning velocity v_0 is denoted as T_0, a given scanning velocity v is expressed as $v=\alpha \times v_o$ (where α is a real number greater than or equal to 1), and a corresponding basic clock period T can be expressed as $T=T_0/\alpha$, the irradiation time T_{mp} of a pulse can be expressed as a function of α:

$$T_{mp}(\alpha)/T(\alpha)=a \times \alpha + b$$

where a and b are constants, $0.1 \leqq a \leqq 0.4$, and $0.1 \leqq b \leqq 0.4$.

13. The information recording method as claimed in claim 11, wherein a relationship $T_{mp}'(v_H)/T_{mp}'(v_L)=T_{mp}(v_H)/T_{mp}(v_L)$ is obtained where $T_{mp}'(v)$ denotes the irradiation time T_{mp} when n=3.

14. The information recording method as claimed in claim 11, wherein $T_{d1}/T(v)$, $T_{d2}/T(v)$, and $T_{d2}'/T(v)$ are fixed regardless of the scanning velocity v.

15. The information recording method as claimed in claim 11, wherein $\delta_1 o/T(v)$, $\delta_2/T(v)$, and $\delta_3/T(v)$ are fixed regardless of the scanning velocity v.

16. An information recording apparatus that records information on an optical information recording medium according to a mark length recording scheme in which a temporal length of a recording mark is represented as nT where n denotes a natural number and T denotes a basic clock period, said information recording apparatus comprising:

a rotation drive structure that rotates the optical information recording medium;
a laser light source that generates a light beam, which is irradiated on the optical information recording medium;
a light source drive unit that administers the laser light source to emit light;
a light emission waveform control unit that controls the light source drive unit when a recording strategy relating to a light emission waveform of the light beam generated by the laser light source is set; and
a speed control unit that controls a relative scanning velocity between the rotation of the optical information recording medium and the light beam irradiated on said optical information recording medium, wherein:

the light emission waveform control unit uses the recording strategy to control the light emission waveform so that:

when $n \geqq 4$, the fall of a first pulse of the multi-pulse sequence is synchronized with the basic clock; and when n is an odd number and $n \geqq 7$, a period from the fall of the first pulse to the fall of a second pulse in the multi-pulse sequence is arranged to be greater than 2T and in synchronization with the basic clock, periods of pulses after the second pulse except for a last pulse of the multi-pulse sequence are arranged to be 2T, and a period from the fall of a second to last pulse to the fall of the last pulse, denoted as $T_1 o$, is set to $T_1 o=(2+\delta_1 o)T$ where $0<\delta_1 o \leqq 1$.

17. The information recording apparatus as claimed in claim 16, wherein:

the light emission waveform control unit controls the period from the fall of the first pulse to the fall of the second pulse when n is an odd number and $n \geqq 7$ to be 2.5T.

18. The information recording method as claimed in claim 16, wherein:

the light emission waveform control unit uses the recording strategy to control the light emission waveform so that when n is an even number and $n \geqq 6$, periods of the pulses after the first pulse of the multi-pulse sequence are set to be 2T, and the period from the fall of the second to last pulse to the fall of the last pulse, denoted as Tie, is set to $T_1 e=(2+\delta_1 e)T$ where $0<\delta_1 e \leqq 1$.

19. The information recording apparatus as claimed in claim 18, wherein the light emission waveform control unit sets $\delta_1 e$ to $\delta_1 e=0$.

20. The information recording apparatus as claimed in claim 16, wherein:

the light emission waveform control unit uses the recording strategy to control the light emission waveform so that when a time from the rise of a logical data pulse to the rise of the first pulse of the multi-pulse sequence when $n \geqq 4$ is denoted as T_{d1} and a time from the rise of a logical data pulse to the rise of the first pulse of the multi-pulse sequence when n=3 is denoted as T_{d13}, $T_{d13}= T_{d1}+\delta_2 T$ where $0<\delta_2 \leqq 1$.

21. The information recording apparatus as claimed in claim 16, wherein:

the light emission waveform control unit irradiates light with an irradiation power Pb between the pulses with the irradiation power Pw in the multi-pulse sequence where Pw>Pb.

22. The information recording apparatus as claimed in claim 21, wherein:

the light emission waveform control unit irradiates light with an irradiation power Pe to record a mark space where Pw> Pe>Pb.

23. The information recording apparatus as claimed in claim 22, wherein:

the light emission waveform control unit uses the recording strategy to control the light emission waveform so that:

a last off pulse with the irradiation power Pb is added after the irradiation of the last pulse with the irradiation power Pw in the multi-pulse sequence;
a pulse with the irradiation power Pe is added after the last off pulse with the irradiation power Pb; and an interval between the rise of the pulse with the irradiation power Pe and the fall of a logical data pulse when $n \geqq 4$ is set to T_{d2} where $-1T \leqq T_{d2} \leqq 1T$, and an interval between the rise of the pulse with the irradiation power Pe and the fall of a logical data pulse when n=3 is set to T_{d2}' where $-1T \leqq T_{d2}' \leqq 1T$.

24. The information recording apparatus as claimed in claim 23, wherein:

the light emission waveform control unit uses the recording strategy to control the light emission waveform so that:

when an irradiation time of the irradiation power Pw of an m^{th} pulse (where m is a natural number), which corresponds to the last pulse of the multi-pulse sequence, is denoted as $T_{on}(n, m)$, and an irradiation time of the irradiation power Pw of a pulse other than the m^{th} pulse is denoted as $T_{on}(n, i)$ where i is a value within a range of 1 through m-1, all the irradiation times $T_{on}(n, i)$ of the multi-pulse sequence, other than the irradiation time when n=3 and the irradiation time of the last pulse when n is an odd number and $n \geqq 5$, are set equal to $T_{on}(n, i)=T_{mp}$ where T_{mp} is a constant and $0.5T \leqq T_{mp} \leqq 1.5T$; and
the irradiation time of the last pulse when n is an odd number and $n \geqq 5$, denoted as $T_{on}(n, m)=T_{1p}$, is set to $T_{1p}=T_{mp}+\delta_3 T$ where $0 \leqq \delta_3 \leqq 1$.

25. The information recording method as claimed in claim 24, wherein the light emission waveform control unit uses the recording strategy to control the light emission waveform so that T_{1p} and T_{mp} are arranged to be fixed values regardless of the optical information recording medium.

26. The information recording apparatus as claimed in claim 24, wherein:

the light emission waveform control unit uses the recording strategy to control the light emission waveform so that:

when differing scanning velocities $v=v_L$ and $v=v_H$ are used in the recording where $V_L < V_H$, the basic clock periods T corresponding to the scanning velocities v_L and v_H are denoted as $T(v_L)$ and $T(v_H)$, respectively, a line density is fixed to obtain a relationship $v_L \times T(v_L)=v_H \times T(v_H)$, the irradiation time T_{mp} upon recording at the scanning velocity v_L is denoted as $T_{mp}(v_L)$, and the irradiation time T_{mp} upon recording at the scanning velocity v_H is denoted as $T_{mp}(v_H)$, the relationships between the irradiation times corresponding to the differing scanning velocities v_L and v_H satisfy conditions $T_{mp}(v_H) < T_{mp}(v_L)$ and $T_{mp}(v_H)/T(v_H) > T_{mp}(v_L)/T(v_L)$.

27. . The information recording apparatus as claimed in claim 26, wherein:

the light emission waveform control unit uses the recording strategy to control the light emission waveform so that:

when a minimum scanning velocity for the recording is denoted as v_0, a basic clock period corresponding to the minimum scanning velocity v_0 is denoted as T_0, a given scanning velocity v is expressed as $v=\alpha \times v_o$ (where α is a real number greater than or equal to 1), and a corresponding basic clock period T is expressed as $T=T_0/\alpha$, the irradiation time T_{mp} of a pulse can be expressed as a function of α:

$$T_{mp}(\alpha)/T(\alpha)=a \times \alpha+b$$

where a and b are constants, $0.1 \leqq a \leqq 0.4$, and $0.1 \leqq b \leqq 0.4$.

28. The information recording apparatus as claimed in claim 26, wherein the light emission waveform control unit establishes a relationship $T_{mp}'(v_H)/T_{mp}'(v_L)=T_{mp}(v_H)/T_{mp}(V_L)$ where $T_{mp}'(v)$ denotes the irradiation time T_{mp} when

$n=3$.

29. The information recording apparatus as claimed in claim 26, wherein the light emission waveform control unit maintains fixed values for $T_{d1}/T(v)$, $T_{d2}/T(v)$, and $T_{d2}'/T(v)$ regardless of the scanning velocity v.

30. The information recording apparatus as claimed in claim 26, wherein the light emission waveform control unit maintains a fixed value for $\delta_{1}o/T(v)$, $\delta_{2}/T(v)$, and $\delta_{3}/T(v)$ regardless of the scanning velocity v.

31. An optical information recording medium on which information is recorded using an information recording method according to a mark length recording scheme in which a temporal length of a recording mark is represented as nT where n denotes a natural number and T denotes a basic clock period, wherein:

the recording mark is formed by a multi-pulse sequence, which is increased by one pulse with an irradiation power Pw for every increase of 2T in the temporal length nT; and
a recording strategy, used in forming the recording mark, controls the multi-pulse sequence so that:

when $n \geqq 4$, the fall of a first pulse of the multi-pulse sequence is synchronized with the basic clock; and
when n is an odd number and $n \geqq 7$, a period from the fall of the first pulse to the fall of a second pulse in the multi-pulse sequence is arranged to be greater than 2T and in synchronization with the basic clock, periods of pulses after the second pulse except for a last pulse of the multi-pulse sequence are arranged to be 2T, and a time from the fall of a second to last pulse to the fall of the last pulse, denoted as T_1o, is set to $T_1o=(2+\delta_1o)T$ where $0<\delta_1o \leqq 1$; wherein
information of δ_1o as a parameter for determining the time T_1o is preformatted on the optical information recording medium.

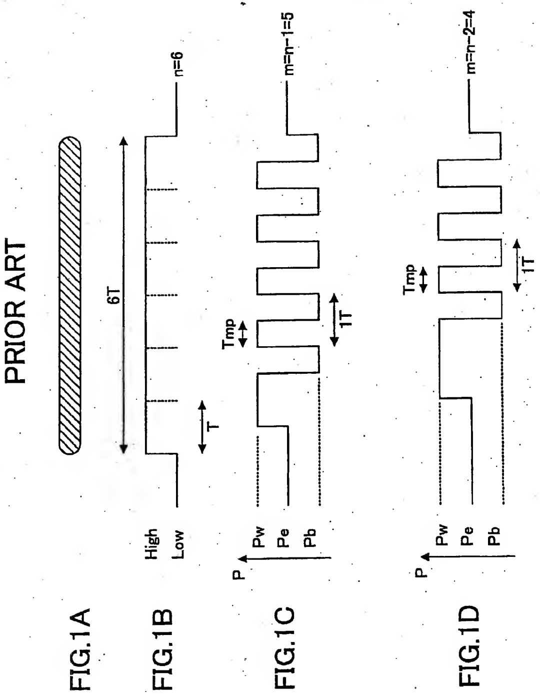


FIG.1A

FIG.1B

FIG.1C

FIG.1D

FIG.2A

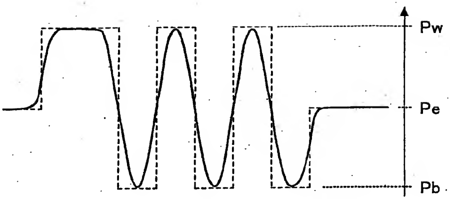


FIG.2B

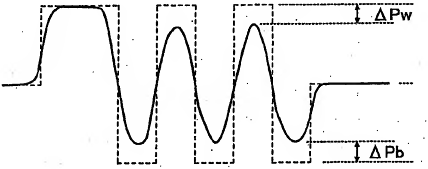


FIG.2C

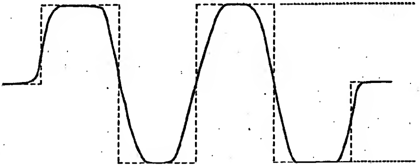


FIG.3

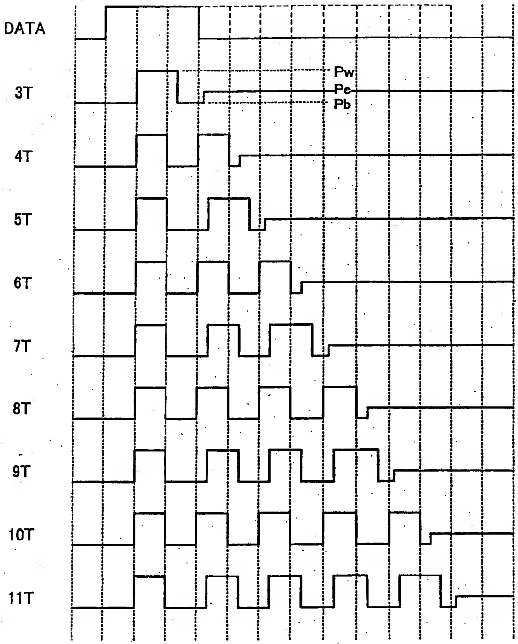


FIG.4

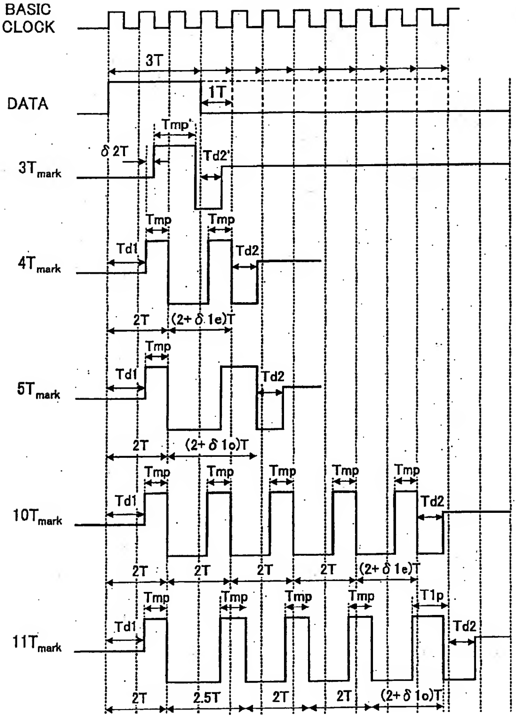

BASIC CLOCK
3T
DATA
1T
Tmp'
δ 2T
Td2'
$3T_{mark}$
Tmp
Tmp
Td1
Td2
$4T_{mark}$
2T
(2+ δ 1e)T
Tmp
Td1
Td2
$5T_{mark}$
2T
(2+ δ 1o)T
Tmp
Tmp
Tmp
Tmp
Tmp
Td1
Td2
$10T_{mark}$
2T
2T
2T
2T
(2+ δ 1e)T
Tmp
Tmp
Tmp
Tmp
T1p
Td1
Td2
$11T_{mark}$
2T
2.5T
2T
2T
(2+ δ 1o)T

FIG.5

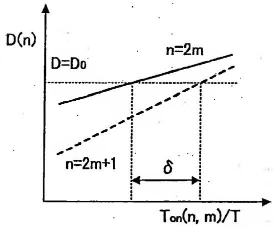


FIG.6

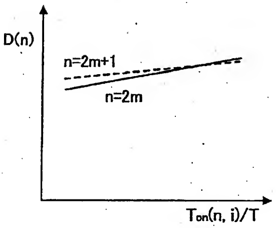


FIG.7

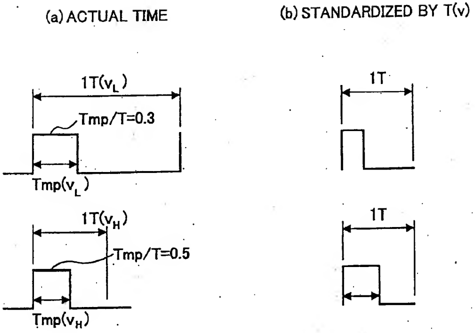

(a) ACTUAL TIME
(b) STANDARDIZED BY T(v)
1T(vL)
Tmp/T=0.3
Tmp(vL)
1T(vH)
Tmp/T=0.5
Tmp(vH)
1T
1T

FIG.8

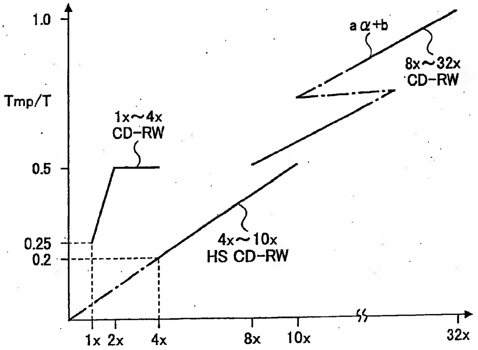

1.0
Tmp/T
0.5
0.25
0.2
aα+b
8x~32x
CD-RW
1x~4x
CD-RW
4x~10x
HS CD-RW
1x
2x
4x
8x
10x
32x

FIG.9

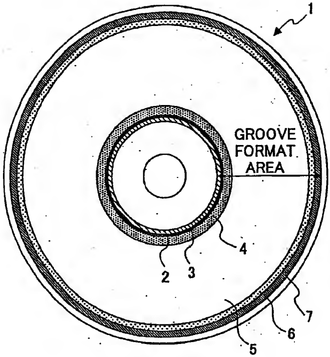

1
GROOVE
FORMAT
AREA
4
2
3
7
6
5

FIG.10

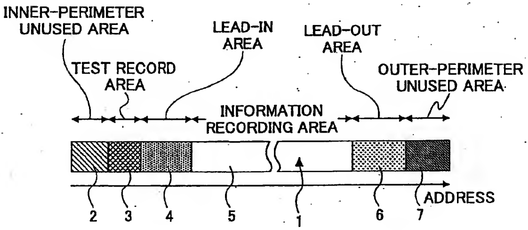
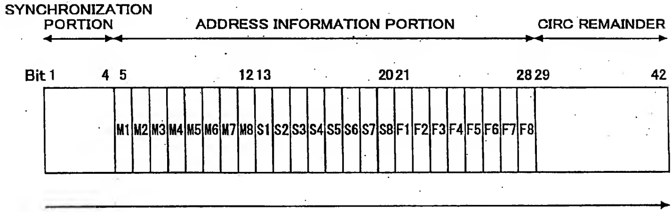

INNER-PERIMETER
UNUSED AREA
LEAD-IN
AREA
LEAD-OUT
AREA
TEST RECORD
AREA
OUTER-PERIMETER
UNUSED AREA
INFORMATION
RECORDING AREA
ADDRESS
2
3
4
5
1
6
7

FIG.11



(M1, S1, F1) = (0, 0, 0) OR (1, 0, 0) : NORMAL ADDRESS

(M1, S1, F1) = (1, 0, 1) : SPECIAL INFORMATION 1

(M1, S1, F1) = (1, 1, 0) : SPECIAL INFORMATION 2

(M1, S1, F1) = (1, 1, 1) : SPECIAL INFORMATION 3

(M1, S1, F1) = (0, 0, 1) : ADDITIONAL INFORMATION 1

(M1, S1, F1) = (0, 1, 0) : ADDITIONAL INFORMATION 2

(M1, S1, F1) = (0, 1, 1) : ADDITIONAL INFORMATION 3

FIG.12

ADDITIONAL INFORMATION 1

Bit 5							12	13							20	21							28
0	M2	M3	M4	M5	M6	M7	M8	0	S2	S3	S4	S5	S6	S7	S8	1	F2	F3	F4	F5	F6	F7	F8

ADDRESS INFORMATION PORTION

(M2, M3, M4) : Td1
(M5, M6, M7) : Td2
(M8, S2, S3) : Td2'
(S4, S5, S6) : Tmp
(S7, S8, F2) : Tmp'
(F3, F4, F5) : δ_{10}
(F6, F7, F8) : δ_2

ADDITIONAL INFORMATION 2

Bit 5							12	13							20	21							28
0	M2	M3	M4	M5	M6	M7	M8	1	S2	S3	S4	S5	S6	S7	S8	0	F2	F3	F4	F5	F6	F7	F8

ADDRESS INFORMATION PORTION

(M2, M3, M4) : δ_3

FIG.13

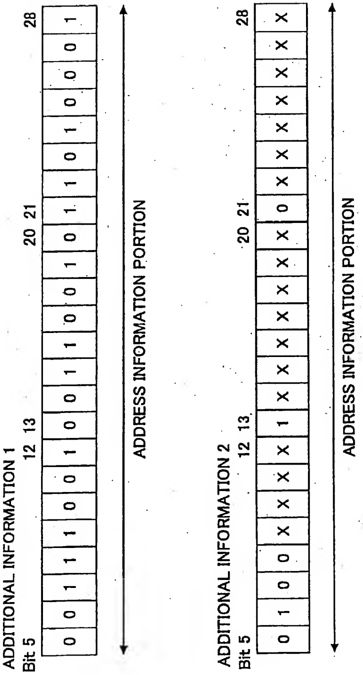

ADDITIONAL INFORMATION 1
Bit 5
12 13
20 21
28
0 0 1 1 1 0 0 1 0 0 1 1 0 0 1 0 1 1 0 1 0 0 0 1
ADDRESS INFORMATION PORTION
ADDITIONAL INFORMATION 2
Bit 5
12 13
20 21
28
0 1 0 0 X X X X 1 X X X X X X X 0 X X X X X X X
ADDRESS INFORMATION PORTION

FIG.14

PARAMETER : Td1

M2	M3	M4	VALUE
0	0	0	Td1 = 0.00
0	0	1	Td1 = 0.25
0	1	0	Td1 = 0.38
0	1	1	Td1 = 0.50
1	0	0	Td1 = 0.63
1	0	1	Td1 = 0.75
1	1	0	Td1 = 0.88
1	1	1	Td1 = 1.00

11a

FIG.15

PARAMETER : Td2

M5	M6	M7	VALUE
0	0	0	Td2/T = −1.00
0	0	1	Td2/T = −0.75
0	1	0	Td2/T = −0.50
0	1	1	Td2/T = −0.25
1	0	0	Td2/T = 0.00
1	0	1	Td2/T = 0.25
1	1	0	Td2/T = 0.50
1	1	1	Td2/T = 1.00

11b

FIG.16

PARAMETER : Td2'

M8	S2	S3	VALUE
0	0	0	Td2'/T = −1.00
0	0	1	Td2'/T = −0.75
0	1	0	Td2'/T = −0.50
0	1	1	Td2'/T = −0.25
1	0	0	Td2'/T = 0.00
1	0	1	Td2'/T = 0.25
1	1	0	Td2'/T = 0.50
1	1	1	Td2'/T = 1.00

11c

FIG.17

PARAMETER : Tmp

S4	S5	S6	VALUE
0	0	0	Tmp/T = 0.50
0	0	1	Tmp/T = 0.63
0	1	0	Tmp/T = 0.75
0	1	1	Tmp/T = 0.88
1	0	0	Tmp/T = 1.00
1	0	1	Tmp/T = 1.17
1	1	0	Tmp/T = 1.33
1	1	1	Tmp/T = 1.50

11d

FIG.18

PARAMETER : Tmp'

S7	S8	F2	VALUE
0	0	0	Tmp'/T = 0.50
0	0	1	Tmp'/T = 0.75
0	1	0	Tmp'/T = 1.00
0	1	1	Tmp'/T = 1.20
1	0	0	Tmp'/T = 1.40
1	0	1	Tmp'/T = 1.60
1	1	0	Tmp'/T = 1.80
1	1	1	Tmp'/T = 2.00

11e

FIG.19

F3	F4	F5	VALUE
0	0	0	δ_{10} = 0.10
0	0	1	δ_{10} = 0.23
0	1	0	δ_{10} = 0.36
0	1	1	δ_{10} = 0.49
1	0	0	δ_{10} = 0.61
1	0	1	δ_{10} = 0.74
1	1	0	δ_{10} = 0.87
1	1	1	δ_{10} = 1.00

11f

FIG.20

F6	F7	F8	VALUE
0	0	0	$\delta_2 = 0.00$
0	0	1	$\delta_2 = 0.25$
0	1	0	$\delta_2 = 0.38$
0	1	1	$\delta_2 = 0.50$
1	0	0	$\delta_2 = 0.63$
1	0	1	$\delta_2 = 0.75$
1	1	0	$\delta_2 = 0.88$
1	1	1	$\delta_2 = 1.00$

11g

FIG.21

F3	F4	F5	VALUE
0	0	0	$\delta_3 = 0.00$
0	0	1	$\delta_3 = 0.07$
0	1	0	$\delta_3 = 0.14$
0	1	1	$\delta_3 = 0.21$
1	0	0	$\delta_3 = 0.28$
1	0	1	$\delta_3 = 0.35$
1	1	0	$\delta_3 = 0.42$
1	1	1	$\delta_3 = 0.50$

11h

FIG.22

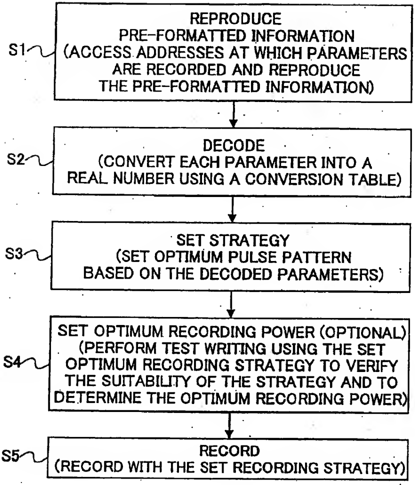

S1
REPRODUCE PRE-FORMATTED INFORMATION (ACCESS ADDRESSES AT WHICH PARAMETERS ARE RECORDED AND REPRODUCE THE PRE-FORMATTED INFORMATION)
S2
DECODE (CONVERT EACH PARAMETER INTO A REAL NUMBER USING A CONVERSION TABLE)
S3
SET STRATEGY (SET OPTIMUM PULSE PATTERN BASED ON THE DECODED PARAMETERS)
S4
SET OPTIMUM RECORDING POWER (OPTIONAL) (PERFORM TEST WRITING USING THE SET OPTIMUM RECORDING STRATEGY TO VERIFY THE SUITABILITY OF THE STRATEGY AND TO DETERMINE THE OPTIMUM RECORDING POWER)
S5
RECORD (RECORD WITH THE SET RECORDING STRATEGY)

FIG.23

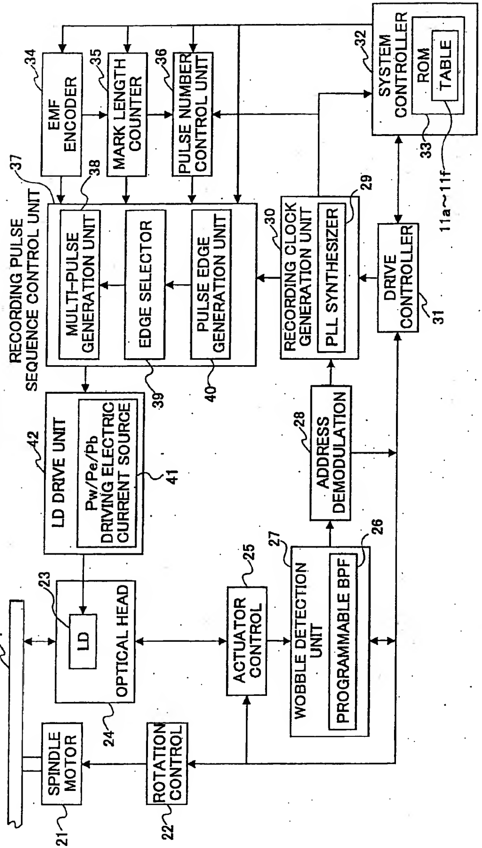
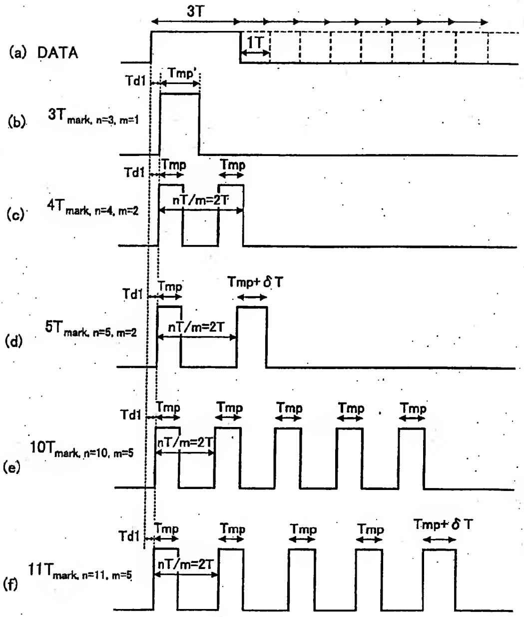

EMF ENCODER
34
MARK LENGTH COUNTER
35
PULSE NUMBER CONTROL UNIT
36
SYSTEM CONTROLLER
32
ROM
TABLE
33
11a~11f
RECORDING PULSE SEQUENCE CONTROL UNIT
37
MULTI-PULSE GENERATION UNIT
38
EDGE SELECTOR
39
PULSE EDGE GENERATION UNIT
40
RECORDING CLOCK GENERATION UNIT
30
PLL SYNTHESIZER
29
DRIVE CONTROLLER
31
LD DRIVE UNIT
42
Pw/Pe/Pb DRIVING ELECTRIC CURRENT SOURCE
41
ADDRESS DEMODULATION
28
WOBBLE DETECTION UNIT
27
PROGRAMMABLE BPF
26
ACTUATOR CONTROL
25
LD
23
OPTICAL HEAD
24
1
SPINDLE MOTOR
21
ROTATION CONTROL
22

FIG.24


3T
(a) DATA
1T
Td1
Tmp'
(b) $3T_{mark,\ n=3,\ m=1}$
Td1
Tmp
Tmp
(c) $4T_{mark,\ n=4,\ m=2}$
nT/m=2T
Td1
Tmp
Tmp+ δ T
(d) $5T_{mark,\ n=5,\ m=2}$
nT/m=2T
Td1
Tmp
Tmp
Tmp
Tmp
Tmp
(e) $10T_{mark,\ n=10,\ m=5}$
nT/m=2T
Td1
Tmp
Tmp
Tmp
Tmp
Tmp+ δ T
(f) $11T_{mark,\ n=11,\ m=5}$
nT/m=2T

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 361 570 A3

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04.10.2006 Bulletin 2006/40

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12.11.2003 Bulletin 2003/46

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(22) Date of filing: 09.05.2003

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G11B 7/0045 (2006.01) *G11B 7/125* (2006.01)

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12.09.2002 JP 2002266501

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Tokyo (JP)

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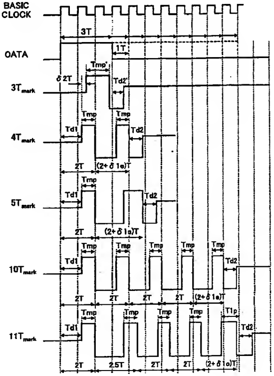
Marks & Clerk
90 Long Acre
London WC2E 9RA (GB)

(54) Information recording method information recording apparatus and optical information recording medium

(57) An information recording technique for forming a recording mark with a multi-pulse sequence, which is increased by one pulse with an irradiation power Pw for every increase of 2T in a temporal length nT of the recording mark is provided. Particularly, this technique realizes a recording strategy that is simple in its configuration but is. capable of improving the consistency of mark shapes in forming the recording marks when the value n of the temporal length nT is an odd number. More specifically, when n is an odd number and $n \geqq 7$, a period from the fall of a first pulse to the fall of a second pulse is set to 2.5T and a period corresponding to a last pulse is set to $(2+\delta_1 o)T$ where the value of $\delta_1 o$ is optimized within a range of $0 < \delta_1 o \leqq 1$. In this way, the multi-pulse sequence can be adjusted from the front pulse side and the rear pulse side so that an overall consistency can be realized in the mark shape upon recording the mark. At the same time, when $n \geqq 4$, the fall of the first pulse is synchronized with a basic clock, and the fall of the second pulse and the rest of the pulses except for the last pulse are also synchronized with the basic clock by irradiating the pulses at periods of 2.5T or 2T. In this way, the design of a recording strategy generation circuit that generates the actual recording strategy can be simplified.

FIG.4



EP 1 361 570 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 03 25 2896

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2001/053115 A1 (NOBUKUNI NATSUKO ET AL) 20 December 2001 (2001-12-20) * page 1, paragraph 8 - page 1, paragraph 10 * * page 2, paragraph 25 * * page 3, paragraph 44 - page 4, paragraph 50 * * page 4, paragraph 82 * * page 5, paragraph 102 - page 6, paragraph 117 * * page 12, paragraph 209 - page 14, paragraph 248 * * page 15, paragraph 257 - page 15, paragraph 262 * * page 16, paragraph 276 * * figure 24 *	1-31	INV. G11B7/0045 G11B7/125
D,X	PATENT ABSTRACTS OF JAPAN vol. 2002, no. 03, 3 April 2002 (2002-04-03) & JP 2001 331936 A (MITSUBISHI CHEMICALS CORP), 30 November 2001 (2001-11-30) * abstract *	1-31	
A	US 5 732 062 A (YOKOI ET AL) 24 March 1998 (1998-03-24) * column 33, line 63 - column 46, line 44 * * figures 32,34,35,38 *	1-31	

TECHNICAL FIELDS SEARCHED (IPC)

G11B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	24 August 2006	Brezmes Alonso, F

2

CATEGORY OF CITED DOCUMENTS

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D : document cited in the application
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& : member of the same patent family, corresponding document

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The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

24-08-2006

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2001053115 A1	20-12-2001	AU 4612500 A	12-12-2000
		CN 1347553 A	01-05-2002
		CN 1619654 A	25-05-2005
		CN 1619655 A	25-05-2005
		EP 1182649 A1	27-02-2002
		WO 0072316 A1	30-11-2000
JP 2001331936 A	30-11-2001	NONE	
US 5732062 A	24-03-1998	NONE	

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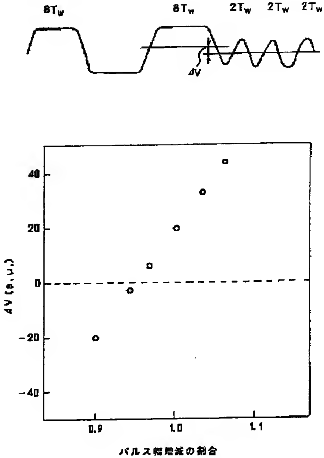
Patent Abstracts of Japan



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TITLE : RECORDING METHOD OF OPTICAL RECORD

ABSTRACT : PROBLEM TO BE SOLVED: To provide a super high density optical recording method by suppressing fluctuation in a recording mark shape due to the fluctuation of recording sensitivity and controlling the recording mark shape with high precision.

SOLUTION: A mechanism is provided in which test recording is performed before the recording of user information by using multi-pulse as a recording waveform that takes into consideration the flow of heat inside a recording medium. In addition, a mechanism is provided which controls pulse width of the recording waveform by using the result of the test recording. By this method, disk recording is always possible at the optimum conditions (domains of the same shape can be formed with high precision), even if the environmental conditions of the use are changed for a recording/reproducing device and a recording medium, and even if the lamination structure of the disk is different.

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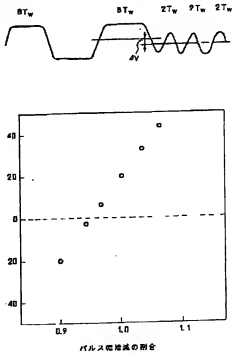
最終頁に続く

(54)【発明の名称】　光記録の記録方法

(57)【要約】
【課題】　本発明の目的は、記録感度の変動による記録マーク形状の変動を抑制し、高精度に記録マーク形状を制御して超高密度光記録方法を提供することである。
【解決手段】　本発明は、記録媒体中の熱の流れを考慮した記録波形としてマルチパルスを用いて、ユーザー情報の記録に先立ちテスト記録を行なう。機構を有する。そして、テスト記録の結果を用いて、記録波形のパルス幅の制御を行なうための、パルス幅を制御する機構を有する。
【効果】　本発明によれば、記録再生装置及び記録媒体の使用環境条件が変動したり、ディスクの積層構造が異なっても、常に最適条件にてディスクへ記録を行なう(同一形状のドメインを高精度に形成できる)ことができる。

図 5



【特許請求の範囲】

【請求項1】少なくともレーザー光を用いて記録を行なう光記録において、ユーザーデータを記録するのに先立って、テスト記録を行なうのに、設定のレーザーのパワーを一定にしておき、テスト記録のパルスの幅を基準となる設定値を中心に増減させてテスト記録を行ない、その結果を再生して統計処理を行ない、得られた結果をもとにユーザーデータを記録するための記録条件を設定し、それにより装置の変動やディスクの記録感度バラツキ等が存在しても、常に同じサイズの記録ドメインを形成するようにテスト記録による記録制御を行なったことを特徴とする光記録の記録方法。

【請求項2】請求項1記載のテスト記録及びユーザーデータの記録に用いる記録波形として、微小パルスの集合体から構成され、先頭のパルスの幅を他のパルスの幅より広く設定し、それより後のパルスの幅及びパルスとパルスの間隔を等しくした記録波形により光ディスクへ記録したことを特徴とする光記録の記録方法。

【請求項3】請求項1及び2記載のテスト記録及びユーザーデータの記録に用いる記録波形において、その設定パワーレベルが少なくとも4つのパワーレベルよりなり、そのレベルの中の最も低いレベルが読み出しレベルで、次のレベルがプリヒートレベルで、そして、残りの2つのレベルが記録レベルであり、さらに、それぞれのパワーレベルに役割を持たせ、読み出しレベルは、記録した情報の再生及び記録した情報の検証を、プリヒートレベルは、パルスとパルスの間における記録媒体の温度が一定となるように熱バランスを取るためのパワーであり、記録レベルは、ディスクへ情報を記録するためのレベルとして用いたことを特徴とする光記録の記録方法。

【請求項4】請求項3記載のテスト記録及びユーザーデータの記録に用いる記録波形における2つの記録レベルにおいて、先頭のパルスとそれ以降に続くパルスとの熱バランスを取り、記録膜の最高到達温度が記録パターンに依存しないで一定となるように設定したことを特徴とする光記録の記録方法。

【請求項5】請求項3及び4記載のテスト記録及びユーザーデータの記録に用いる記録波形において、第1の記録レベル或いは第2記録レベルとプリヒートレベルとの比、及び第1の記録レベルと第2記録レベルとの比をディスクの積層構造或いは記録媒体として用いる材料により変化させて設定したことを特徴とする光記録の記録方法。

【請求項6】請求項1～5記載のテスト記録及びユーザーデータの記録に用いる記録波形において、記録パルスを照射した後に一定期間のリードレベルを経た後に、一定期間のプリヒートレベルへ移行し、再び、記録領域へ入ることにより、記録パターン間の熱的干渉を除去したことを特徴とする光記録の記録方法。

【請求項7】請求項6記載のテスト記録及びユーザーデータの記録に用いる記録波形において、記録パルスを照射した後の一定期間のリードレベル及びプリヒートレベルの時間がライトクロックに同期した期間であることを特徴とする光記録の記録方法。

【請求項8】請求項1～7記載のテスト記録及びユーザーデータの記録に用いる記録波形において、基準となる記録条件における記録パルスのパルス幅及びパルスとパルスの間隔をライトクロックに同期させたことを特徴とする光記録の記録方法。

【請求項9】請求項1～8記載のテスト記録において、一定のパターンをテストトラックへ記録し、それを再生し、結果を統計処理することにより、レーザーパワーの変動、フォーカスの変動、トラック位置ずれ、或いは、環境温度変動等の記録条件の変動を検出し、その結果をもとに微小パルスより構成される記録波形における各微小パルスのパルス幅を変化させて記録することにより、記録条件の変動によらず常に同一形状の記録ドメインを光ディスクへ記録できるように制御したことを特徴とする光記録の記録方法。

【請求項10】請求項1～9記載の記録において、情報を記録するのに形成したマークのエッジ部分に情報を記録するマーク長記録方式により行なったことを特徴とする光記録の記録方法。

【請求項11】請求項1～10記載のテスト記録において、一定のパターンをテストトラックへ設定パワーを変化させずに基準のパルス幅を中心に一定の割合で変化させて記録し、それを再生し、用いるパターンとして記録に用いる変調方式における最も短いパターンとパルス間隔の繰返しと最も長いパターンと最も短いパルス間隔の繰返しとを交互に記録し、それを再生したときの両パターンの信号振幅の中心位置の電圧の差を検出することにより、記録条件の変動を検出し、その電位差がほぼゼロとなるパルス幅を検出することにより、同一形状のドメインを得たことを特徴とする光記録の記録方法。

【請求項12】請求項1～11記載の最適記録条件を検出するためのテスト記録において、一定時間間隔毎或いは記録命令が発せられた後にテスト記録を行なってから、情報を記録したことを特徴とする光記録の記録方法。

【請求項13】請求項1～12記載のテスト記録により検出した最適記録条件にて、1枚の光ディスクにおいて、それを複数のゾーンに分割し、少なくとも各ゾーンのいずれの位置においても記録密度が等しくなるように記録したことを特徴とする光記録の記録方法。

【請求項14】請求項1～13記載の最適記録条件を検出するためのテスト記録において、複数のゾーンに分割した光ディスクにおいて、各ゾーンの一定領域へテスト記録を行なった後に記録したことを特徴とする光記録の記録方法。

【請求項15】請求項1～14記載の光記録の記録方法

により、光磁気ディスクを用いてそれに記録したことを特徴とする光記録の記録方法。

【請求項16】請求項1〜14記載の光記録の記録方法により、ユーザーが情報を1回だけ記録できる追記型光ディスクへ記録したことを特徴とする光記録の記録方法。

【請求項17】請求項15記載の追記型光記録において、ディスクローディング時或いは装置起動時に情報をディスクへ記録する前に、ディスクへ一定のパターンを用いてテスト記録を行い、そのテスト記録したデータを再生し、その結果を統計処理を行なうのに、その結果を用いて用いるレーザー光源から発射されるパワーを制御することにより、常に同一のサイズの記録ドメインを形成したことを特徴とする光記録の記録方法。

【請求項18】請求項15及び請求項16記載の追記型光記録において、あらかじめディスクの一定領域に基準となる一定のパターンの信号を記録しておき、ディスクローディング時或いは情報をディスクへ記録する前に、ディスクへ一定のパターンを用いてテスト記録を行い、そのテスト記録したデータを再生し、その結果を統計処理を行い、その結果とあらかじめ記録してある信号とを比較して最適パワーを求め、記録条件等の変動の影響を受けることなく常に同一のサイズの記録ドメインを形成したことを特徴とする光記録の記録方法。

【請求項19】請求項15〜17記載のディスクへテスト記録を少なくともディスク駆動装置起動時或いは駆動装置へディスクをローディングした時に行ったことを特徴とする光記録の記録方法。

【請求項20】請求項15〜18記載のディスクが追記型の光ディスクであり、その情報の記録方法として記録層の反射率の変化を用いて行い、さらに優位にはその反射率の変化を記録層の結晶状態の変化、屈折率の変化、再生に用いる光の波長における光吸収率の変化、合金部分の形成による光反射率の変化、光の乱反射する層の形成、或いは、記録層の消失部分の形成の内より選ばれる少なくとも1種類の方法を用いたことを特徴とする光記録の記録方法。

【請求項21】請求項1〜19記載のディスクへ記録した情報をディジタルな電気信号として再生するのに、得られた再生信号を一定レベルでスライスを行うことにより2値化し、さらに優位にはそのスライスレベルが得られた信号の振幅の中心値であることを特徴とする光記録の記録方法。

【発明の詳細な説明】

【0001】

【発明の属する技術分野】本発明は、少なくともレーザー光を用いて記録、再生、或いは消去を行なう光記録に係り、特に、超高密度光記録に好適な光記録の記録方法に関する。

【0002】

【従来の技術】近年の高度情報化社会の進展にともない高密度で大容量なファイルメモリーへのニーズが高まっている。これに応えるものとして、光記録が注目されており多くの研究機関で研究開発が進められている。この中で、最近では書換え型の光磁気ディスクが実用化され、文書ファイルや画像ファイル等に用いられている。ところで、第1世代光磁気ディスクが実用化されて以来、高性能化を目指して検討が進められており、第3世代追記型光記録も同時に高性能化が検討されている。

【0003】高性能化の1つに、記録容量の大容量化をあげることができる。記録容量の増大を図るためには、1)トラックピッチをつめる、2)マーク長記録を行なう、3)ビットピッチをつめる、4)変調方式を工夫する、5)波長の短いレーザー光を用いる、6)MCAV方式を用いる、等の手法が提案されている。これらの手法を用いて記録/再生/消去を行なう場合に、重要なのは、如何なる記録条件のもとでも常に同じ形状の記録ドメインが得られることである。この点につき検討した公知例として、特開平3-22223号をあげることができる。この公知例では、記録マークの記録符号列をパルス化して記録符号列の長さに対応する一連のパルス列を形成し、パルス列の長さ、振幅を記録符号列の直前にある記録符号列の逆相の長さに応じて制御し、パルス列の3つの部分に分け、各パルスのパルス幅を変化させて記録を行なう方式となっていた。

【0004】

【発明が解決しようとする課題】上記従来技術では、マーク長記録方式におけるディスクの記録媒体の各層の膜厚変動や環境温度変動による記録媒体に対する記録感度変動やそれに基づくエッジシフト、或いはサーボ系の変動によるエッジシフトが発生する点について必ずしも十分な配慮がなされているとは限らなかった。例えば、超高密度光記録に必要な高精度の記録マーク形状を制御できない場合があった。

【0005】そこで、本発明の第1の目的は、前記記録感度の変動による記録マーク形状の変動、及び、エッジシフトを極力抑制し、高精度な記録マーク形状制御法を提供することにより、超高密度光記録を提供することにある。本発明の他の目的は、記録再生装置と記録媒体との整合性を向上させるとともに、記録再生装置による記録感度変動及びエッジシフトを抑圧することにある。さらに、本発明の他の目的は、記録再生装置の信頼性および記憶容量や情報の転送レートを向上させることにある。

【0006】

【課題を解決するための手段】上記目的を実現するために、記録再生装置と記録媒体との整合性を向上させる必要がある。特に、光ディスクは可換媒体であることから、記録再生装置のバラツキ、記録媒体のバラツキ等により互換性を確保する場合の障害となる場合がある。特

に、高密度記録を実現する場合には、これらのバラツキを最大限小さくすることが必要であるが、それには限界があった。そこで、このバラツキを吸収するために、ユーザーデータを記録するのに先立って、ディスクの一定の位置にテスト記録を行ない、そのテスト記録によって得られる再生信号とテスト記録パターンデータとを比較し、その差が一定の値以下になった後に、ユーザーデータを記録する。このテスト記録を行なう目的は、マーク長記録方式におけるディスクの記録媒体の各層の膜厚変動や環境温度変動による記録媒体に対する記録感度変動、或いは、記録再生装置のレーザーパワーの変動、さらに、それらに基づくエッジシフト、或いは、サーボ系の変動により発生するエッジシフトを検出して、それを抑制することである。ここで、サーボ系の変動は、フォーカスの変動やトラック位置ずれ等で、これによりエッジシフトを生じる。この他、光ディスクが可換媒体であることを考慮すると、光ヘッドの組立て過程で生じる収差によってもエッジシフトは生じる。記録再生装置間での互換性のことを考慮すると、収差は一定量以下に抑制しなければならない。それと同時に、等化器を用いて、前エッジ部分或いは後エッジ部分での再生信号の波形の傾きを記録したパターンに依存しないで一定の値にすることにより補正できる。

【0007】そこで、少なくともレーザー光を用いて記録、再生、或いは消去を行なう光記録において、ユーザーデータを記録するのに先立って、テスト記録を行なうのに、レーザーのパワーを一定値にしておき、テスト記録のパルスの幅を基準となる設定値を中心に増減させてテスト記録を行ない、その結果を再生して統計処理を行ない、得られた結果をもとにユーザーデータの記録条件を設定すればよい。ここで言うテスト記録やユーザーデータの記録に用いる記録波形を構成する微小パルスのパルス幅を、テスト記録において標準設定値を中心に、一定時間間隔で変化させて記録を行なうことにより、記録媒体と記録再生装置とのマッチングが取れた最適な記録条件を決定することができる。このテスト記録及びユーザーデータの記録に用いる記録波形として、微小パルスの集合体から構成され、先頭のパルスの幅を他のパルスの幅より広く設定し、それより後のパルスの幅及びパルスとパルスの間隔を等しくした記録波形により光ディスクへ記録することが好ましい。さらに、このテスト記録及びユーザーデータの記録に用いる記録波形において、その設定パワーレベルが少なくとも4つのパワーレベルよりなり、そのレベルの中の最も低いレベルが読み出しレベルで、次のレベルがプリヒートレベルで、そして、残りの2つのレベルが記録レベルであり、さらに、それぞれのパワーレベルに役割を持たせる。読み出しレベルは、記録した情報の再生及び記録した情報の検証を行うためにあり、プリヒートレベルは、パルスとパルスの間における記録媒体の温度が一定となるように熱バランスを取るためのパワーを供給し、記録レベルは、ディスクへ情報を記録するためのレベルとして用いる。このテスト記録及びユーザーデータの記録に用いる記録波形における2つの記録レベルの設定では、先頭のパルスとそれ以降に続くパルスとの熱バランスを取り、記録膜の温度がパターンに依存しないで一定となるように設定する。この熱バランスを取る場合も、レーザーパワーで制御するよりもパルス幅(時間)で制御した方が制御性におよぼす影響が著しく大きいので記録ドメイン形状制御法として有効である。テスト記録及びユーザーデータの記録に用いる記録波形において、第1の記録レベル或いは第2記録レベルとプリヒートレベルとの比、及び第1の記録レベルと第2記録レベルとの比は、ディスクの積層構造或いは記録媒体として用いる材料により変化させて設定される。そのため、第1記録レベルと第2記録レベルとが等しく設定される場合もでてくるのは言うまでもない。これは、媒体の構造や用いる材料により、媒体中を流れる熱の流れ方が異なるためである。テスト記録及びユーザーデータの記録に用いる記録波形において、記録パルスを照射した後に一定期間のリードレベルを経た後に、一定期間のプリヒートレベルへ移行し、再び、記録領域へ入ることにより、記録パターン間の熱的干渉を除去することができる。テスト記録及びユーザーデータの記録に用いる記録波形において、記録パルスを照射した後の一定期間のリードレベル及びプリヒートレベルの時間がライトクロックに同期した期間である。これは、高精度のクロックを発生できるとともに、装置の作り勝手がよいからである。また、テスト記録において、一定のパターンをテストトラックへ記録し、それを再生し、結果を統計処理することにより、レーザーパワーの変動、フォーカスの変動、トラック位置ずれ、或いは、環境温度変動等の記録条件の変動を検出し、その結果をもとに微小パルスより構成される記録波形における各微小パルスのパルス幅を変化させて記録することにより、記録条件の変動によらず常に同一形状の記録ドメインを光ディスクへ記録できるように制御すればよい。情報を記録する場合において、情報を記録するのに、形成したマークのエッジ部分に情報を記録するいわゆるマーク長記録方式により行なう場合が、特に有効である。また、テスト記録において、一定のパターンをテストトラックへ設定パワーを変化させずに基準のパルス幅を中心に一定の割合で変化させて記録し、それを再生し、用いるパターンとして記録に用いる変調方式における最も短いパターンとパルス間隔の繰返しと最も長いパターンと最も短いパルス間隔の繰返しとを交互に記録し、それを再生したときの両パターンの信号振幅の中心位置の電圧の差を検出することにより、記録条件の変動を検出し、その電位差がゼロとなるパルス幅を検出することにより、記録条件に依存しないで、同一形状のドメインを得ることができる。ところで、このテスト記録は、記録を行なう前に行

なうことが必要であることは言うまでもないが、最適記録条件を検出するためのテスト記録であるから、記録や消去の命令がいつくるかわからないので、一定時間間隔毎に行なうことが時間的な効率がよい。ところで、テスト記録により検出した最適記録条件にて、１枚の光ディスクにおいて、それを複数のゾーンに分割し、少なくとも各ゾーンのいずれの位置においても記録密度が等しくなるように記録した所謂ＺＣＡＶ方式を用いることが好ましい。そして、最適記録条件を検出するためのテスト記録を行なうのに、１枚のディスクを複数のゾーンに分割し、各ゾーンの一定領域へテスト記録を行なった後にユーザー情報を記録すればよい。このテスト領域はあらかじめ設定しておく必要がある。

【０００８】マルチパルスを用いた記録波形を用いた記録磁区形状制御の制御性の向上のためにテスト記録方式とを併用することが有効であった。さらに、この方式を用いると、使用環境条件の変動に対して精密に制御できるだけでなく、この他に、ディスクの内周と外周などの位置による記録感度の違いや、ディスク間の感度バラツキ、或いは積層構造のことなるディスク間の互換性の確保にとっても本発明は有効に機能する。特に、超高密度記録を実現するには微妙な磁区形状制御が必要であり、本発明のパルス幅の制御はレーザーパワーを変化させて記録条件を制御する場合よりさらに制御性の向上に大きく寄与する。特に、温度に対して敏感な光磁気記録においては、特に精密な制御を行なう必要があり、その目的を実現するには本発明は、特に、有効である。

【０００９】さらに、追記型光ディスクにおける記録ドメインサイズの変動を生じる原因を解析すると、その主な原因はレーザーパワーの変動である。これは、記録時の記録膜の温度は、４００～５００℃と著しく高いために、室温の変動による記録時の記録膜の温度の上昇が記録ドメインサイズに及ぼす影響は無視できるからである。そこで、追記型光ディスクの記録において、ディスクをローディング時や装置起動時にレーザーパワーを変動を検出する操作を取り入れることにより記録ドメインのサイズの変動を抑制できる。さらに具体的には、少なくともレーザー光を用いて記録或いは再生を行う光記録において、ディスクローディング時或いは情報をディスクへ記録する直前に、ディスクへ一定のパターンを用いてテスト記録を行い、そのテスト記録したデータを再生し、その結果を統計処理を行い、その結果を用いて用いるレーザー光源のパワーを制御することにより、記録条件等の変動の影響を受けることなく常に同一のサイズの記録ドメインを形成することができる。或いは、少なくともレーザー光を用いて記録或いは再生を行う光記録において、あらかじめディスクの一定領域に基準となる一定のパターンの信号を記録しておき、ディスクローディング時或いは情報をディスクへ記録する直前に、ディスクへ一定のパターンを用いてテスト記録を行い、そのテスト記録したデータを再生し、その結果を統計処理を行い、その結果とあらかじめ記録してある信号と比較して最適パワーを求め、記録条件等の変動の影響を受けることなく常に同一のサイズの記録ドメインを形成することができる。ところで、あらかじめディスクの一定領域に記録する基準となる一定のパターンの信号として、形成する記録ドメインの幅或いは長さが異なることが必要である。ディスクへ一定のパターンの情報を記録するのに、マーク長記録方式を用いた場合が好適である。情報を記録するのに用いるディスクとして、ユーザーが情報を１回だけ記録できる追記型の光ディスクである。ここで、情報を記録するのに、情報の記録密度がディスクのいずれの位置においても等しくなるように記録し、さらに優位には、ディスクが複数のゾーンに分割され、そのゾーン毎に記録条件を設定することにより記録することが望ましい。さらに、ディスクへテスト記録を行うのに、ゾーン毎にテスト領域を設け、その中の少なくとも１つのゾーンの中のテスト領域を用いて行い、その結果を解析することにより、レーザーパワーの検出を行ない、記録条件を最適化すればよいことはいうまでもない。ここで、結果の解析手法として統計的な処理を行なうことが好ましい。ディスクへテスト記録を行うのに、少なくともディスク駆動装置起動時或いは駆動装置へディスクをローディングした時に行なえばよい。ここで、ディスクへ記録を行うのに形成される記録ドメインにおいて、形成されるドメインのディスクの半径方向の長さをディスクの回転方向のドメインの長さに依存しないで一定の長さとすれば良い。ここで、用いるディスクとして追記型の光ディスクであり、その情報の記録方法として記録層の反射率の変化を用いて行い、さらに優位にはその反射率の変化を記録層の結晶状態の変化、屈折率の変化、再生に用いる光の波長における光吸収率の変化、合金部分の形成、光の乱反射する層の形成、或いは、記録層の消失部分の形成の内より選ばれる少なくとも１種類の方法を用いて記録を行なう手法を用いて記録すれば良い。ディスクへテスト記録を行うのに用いる記録のパターンとして、用いる変調方式において少なくとも最も長いパターンと最も短いパターンを含んだパターンを用いればよい。ここでは、記録ドメイン間の熱的干渉を検出することが目的ではなく、ドメインサイズの変動の検出が目的である。また、ディスクへテスト記録を行うのに用いる記録のパターンとして、用いる変調方式において少なくとも最も長いパターンと最も短いパターンを含んだパターンを用い、さらに優位にはそのパターンを異なるレーザーパワーを用いて記録することにより、最適なレーザーパワーを検出すればよい。ディスクへテスト記録を行うのに用いる記録パワーとして、ディスク或いはディスク駆動装置のメモリーに記録された標準的な記録条件を中心に記録のパワーもしくはパルス幅を標準的な条件と比較して増加及び減少させた条件により記録す

ればよい。ここで、一定の再生信号出力が得られる記録パワーを求めれば良い。ディスクへテスト記録を行ないレーザーパワーの変動の検出を行なうのに、用いる変調方式において少なくとも最も長いパターンと最も短いパターンの信号振幅の中心値の差を検出することにより行い、最適な記録パワーとしてその中心値のずれ量が最小となるように記録パワーを制御することにより記録ドメインの形状を制御すればよい。ここで、記録した情報を復調するのに、ディスクへ記録した情報をディジタルな電気信号として再生し、得られた再生信号を一定レベルでスライスを行うことにより２値化し、さらに優位にはそのスライスレベルが得られた信号の振幅の中心値を求めて再生することにより復調したものである。

【００１０】普通は追記型光記録では、書換えができないのでテスト記録を行なうとそれだけ記録領域が減少する。しかし、テスト記録に用いるパターンをテスト記録の領域を1セクタ内にパワーを変化させて記録したあらゆるパターンを記録する等用いるパターンを工夫することにより用いるバイト数を節約できる。また、テスト記録も記録に先立って記録のたび毎に行なう必要はなく、レーザー光の変動が考えられるディスクドライブの起動時やディスクのローディング時のみに行なえばよい。通常のテスト記録に必要とするバイト数は50バイト程度であり、ディスクへテスト記録を行なう回数は10^5回程度と考えられ、それに必要とする容量は70MBであり、本発明により記録できる容量は7～10GBで1%以下であり、十分許容できる値である。

【００１１】本発明によれば、ユーザー情報の記録に先立ってテスト記録を行ない、形成される記録磁区の変動を検出することにより、記録条件の変動を見出し、それを補正することにより、常に、同一形状の記録ドメインを形成することができる。これは、いかなる使用環境条件でも、また、異なる記録再生装置や記録媒体用いても、本発明のテスト記録を行なうことにより、標準記録条件からのずれが検出できるので、検出結果をもとに記録条件を制御することにより、システムが置かれている環境条件や装置、媒体の差異による記録感度の変動に基づくエッジシフトやジッタの変化を抑制できる。

【００１２】上記手法により、ユーザー情報を記録する前に、ディスク駆動装置を起動したときもしくはディスクをローディングしたときにテスト記録を行なうことにより、最適なレーザーパワーにて記録できるので、常に同一サイズの記録ドメインが形成できるので、高密度記録が実現できる。ここで、追記型光ディスクはテスト記録を行なう毎に記録領域が少なくなるが、テスト記録を実行するのは、ディスク駆動装置を起動したときもしくはディスクをローディングしたときのみであるから、その時に使用する領域は僅かであるので、全体の記録容量に比べれば僅かである。

【００１３】

【発明の実施の形態】（実施例１）本発明の詳細を実施例を用いて説明する。まず、用いた光磁気ディスクの断面構造を示す模式図を図１に示す。表面に凹凸の案内溝を有するプラスチックもしくはガラスの基板(1)上に、窒化シリコン膜(2)をスパッタ法により形成した。その時の膜厚は75nm である。次に、真空を破ることなく連続して光磁気記録膜(3)を形成した。膜厚は25nmである。そして、再び、窒化シリコン膜(4)をスパッタ法により形成した。その時の膜厚は25nm である。最後に、$Al_{98}Ti_2$金属膜(5)をスパッタ法により形成した。その時の膜厚は50nm である。この記録媒体表面を紫外線硬化型樹脂(6)により保護コートした。このようにして作製したディスクを記録媒体が形成されている面同志が向いあうように２枚のディスク単板を張り合わせた。

【００１４】このようにして作製したディスクへ信号を記録した。用いた記録再生装置の概略を図２に示す。記録再生装置は情報を記憶させるための記録媒体(101)と記録再生を実現するための光ヘッド(102)と、光ヘッド(102)から得られた再生信号を情報に変換する処理系から構成される。光ヘッド(102)はレーザー(108)から出射される光を記録媒体(101)上に絞り込む。情報の記録時は入力データビット列(情報)が、符号器(104)に入力され、符号器(104)から出力される記録符号列が記録波形生成器(105)に導かれ、記録波形生成器(105)によって得られる記録波形がＡＰＣ(オートパワーコントローラ)(106)に入力され、記録符号列に応じた光強度がレーザ(108)から出力される。情報の再生時は記録媒体(101)から反射された光が受光器(109)に導かれ、電気信号に変換される。その信号は、再生アンプ(110)に入力され、波形等化器(111)と入力切換器(112)に出力される。入力切換器(112)は試書き指令信号に応じて再生アンプ(110)または波形等化器(111)のいずれかの再生信号の有無を表すパルス信号に変換される。そのパルス信号は、弁別器(115)とPLL(位相ロックループ)(114)に導かれる。PLL(114)から出力される同期信号(パルス信号の基本周期に同期した信号)は、弁別器(115)に入力される。弁別器(115)は、上記パルス信号と同期信号から検出符号列を生成し、復号器(117)によってデータビット列(情報)を出力する。また、弁別器(115)の検出符号列は、比較判別器(116)に出力される。比較判別器(116)は、試し書き指令信号によって動作する試書き器(103)からの試し書きデータが符号器(104)に出力し、また、試し書き指令信号によって動作する入力切り換え器(112)は、再生アンプ(110)の出力を整形器(113)に出力するように切り換え、符号器(104)からの記号符号列と弁別器(115)からの再生符号列とを比較し、記号符号列からの再生符号列の差異がある程度小さくなって、許容できる範囲で試し書き終了信号を出力する。試し書き終了信号が出力されてから、入力切り換え器(112)は波形等化器(111)の出力を整形器(113)に出力するように切り換え、正規の記録再生

動作を開始する。正規の記録動作を開始した後も、比較判別器(116)で記録符号列からの再生符号列の差異が許容できる範囲であることを確認するようにし、許容できない場合は、前述の試し書き動作を開始させ、試し書き終了信号が出力されたら、再度、正規の記録動作を続ける。また、比較判別器(116)で記録符号列からの再生符号列の差異を確認する場合、入力切り換え器(112)の出力が、再生アンプ(110)の信号を出力するように動作させた方が精度よく検出できる。これらの動作において、入力切り換え器(112)を用いなくても同様な動作を実現できる。比較判別器(116)で記録符号列からの再生符号列の差異を精度よく検出するためには、波形等化器(111)を用いない方がよい。

【0015】上記で説明した記録再生装置及び記録媒体を用いてディスクに記録/再生を行なった。用いた装置のディスクの回転数は3000rpm、レーザーの波長は780nm、そして、変調方式には(1,7)RLLを用いた。ここで、記録密度はディスクのいずれの位置においても等しくなるように記録した。そして、このディスクに記録するのに用いた記録波形を図3に示す。用いたレーザーパワーは、リードレベル(Pr)を1.5mW、プリヒートレベル(Pas)を3.5mW、第1記録レベル(Pw1)を5.8mW、そして、第2記録レベル(Pw2)を6.1mW に設定した。ここで、各パワーの値はディスクの積層構造や用いている材料によって変動するものである。しかし、記録ドメイン間の熱的な干渉により生じるジッタやエッジシフト等を一定値以下に抑制するのに最も大きな効果があるのは、用いる材料を除けばディスクの積層構造である。これを記録再生装置のパラメータで評価すると、Pw1/Pas, Pw2/Pas, Pw1/Pw2の比が一定の範囲内にあることが必要である。多くのディスクについてこの値を測定してみると、1.5<Pw1/Pas<1.7, 1.6<Pw2/Pas<1.8, 0.9<Pw1/Pw2<1.1の範囲内にあるディスクは、マーク長記録を行なう場合、形成される記録ドメインの長さや幅を精密に制御できた。その時の制御精度は、ドメインの長さ(ディスクのトラック方向)が±0.02μm 以下であり、また、ドメインの長さ方向(ディスクの半径方向)が±0.05μm以下であった。この精度は、再生したときのジッタ及びエッジシフトの測定と、MFM(走査磁気力顕微鏡)による測定の両方から求めた値である。そして、5.25″ ディスクの最内周部分のゾーンに記録/再生を試みた。まず、室温(20℃)において先の設定パワーにて(1,7)RLL方式を用いてランダムパターンを記録した。その時のジッタ分布を図4に示す。これは、PLLをかけないで測定した結果である。これによると、対窓幅比で39%であった。また、エッジシフト量を測定したところ、±2ns以下に抑制できていた。この記録再生装置及び媒体を50℃の環境中に放置したところ、ジッタは対窓幅比で50%に増大した。また、シフトも±10nsに大きく増大した。この状態で、この光磁気ディスクにテスト記録を行なった。用いたテストパターンは、2Twと8Twとの繰返しである。ここで、テスト記録を行なうのに、パルス幅を一律 ±3% ±6% ±10% と変化させて記録したときの最長パターンと最短パターンの信号振幅の中心値の差の変化を調べた。パターン間の電位差(ΔV)を検出した結果を図5に示す。この図から、ΔV=0となるパルス幅を求めたところ、この条件では室温条件より 5% 小さくした場合である。そこで、5%一律にパルス幅を削った条件で記録したところ、ジッタは、対窓幅比で39%であった。また、エッジシフト量を測定したところ、±2ns以下に抑制でき、先の標準の記録条件及び標準環境で記録した場合と同じであった。また、逆に、記録再生装置及び記録媒体を0℃中に放置した。テスト記録を行なうことなく装置に設定されている記録条件により記録を行なうと、ジッタは対窓幅比で65%に増大した。また、シフトも±15nsに大きく増大した。

【0016】この状態で、この光磁気ディスクにテスト記録を行なった。用いたテストパターンは、2Twと8Twとの繰返しである。ここで、テスト記録を行なうのに、パルス幅を一律 ±3% ±6% ±10% と変化させて記録したときの最長パターンと最短パターンの信号振幅の中心値の差の変化を調べた。パターン間の電位差(ΔV)を検出した結果を図6に示す。この図から、ΔV=0となるパルス幅を求めたところ、この条件では室温条件より 7% 大きくした場合である。そこで、7%一律にパルス幅を増加させた条件でユーザー情報の形態を想定してランダムパターンを記録したところ、ジッタは、対窓幅比で39%であった。また、エッジシフト量を測定したところ、±2ns以下に抑制でき、先の標準の記録条件及び標準環境で記録した場合と同じになった。

【0017】さらに、別の実施例について述べる。この例は、ディスクの積層構造が異なる場合である。用いた光磁気ディスクは、先の図1に示す構造のディスクIと図7に示す構造のディスクIIの2枚である。ディスクIの構造については先に述べたとおりである。ディスクIIは、表面に凹凸の案内溝を有するプラスチックもしくはガラスの基板(1)上に、窒化シリコン膜(2)をスパッタ法により形成した。その時の膜厚は75nm である。次に、真空を破ることなく連続して光磁気記録膜(3)を形成した。膜厚は100nmである。そして、再び、窒化シリコン膜(4)をスパッタ法により形成した。その時の膜厚は200nm である。この記録媒体表面を紫外線硬化型樹脂(6)により保護コートした。このようにして作製したディスクを記録媒体が形成されている面同志が向いあうように2枚のディスク単板を張り合わせた。

【0018】この2種類のディスクへ標準の記録条件及び標準環境で記録した。記録再生装置へ設定されている記録条件はディスクIにマッチした値であるから、この条件で記録したときのジッタは対窓幅比で39%であり、エッジシフト量は±2ns以下であった。次に、この条件

でディスクIIへ記録すると、ジッタは対窓幅比で50%に増大した。また、シフトも±10nsに大きく増大した。この状態で、この光磁気ディスクにテスト記録を行なった。用いたテストパターンは、2Twと8Twとの繰返しである。ここで、テスト記録を行なうのに、パルス幅を一律±3% ±6% ±10% と変化させて記録したときの最長パターンと最短パターンの信号振幅の中心値の差の変化を調べた。パターン間の電位差(ΔV)を検出した結果を図8に示す。この図から、ΔV=0となるパルス幅を求めたところ、この条件では室温条件より 5%小さくした場合である。そこで、5%一律にパルス幅を削った条件でユーザー情報の形態を想定してランダムパターンを記録したところ、ジッタは、対窓幅比で39%であった。また、エッジシフト量を測定したところ、±2ns以下に抑制でき、先のディスクIへ記録した場合と同じにできた。このように、ディスクの積層構造が異なってもテスト記録を行なうことにより、常に最適条件にてディスクへ記録を行なう(同一形状の磁区を高精度に形成できる)ことができる。ディスクの積層構造が異なると同時に、記録再生装置及び記録媒体を使用する環境が異なってもテスト記録を行なうことにより常に最適条件にてディスクへ記録を行なう(同一形状の磁区を高精度に形成できる)ことができることは言うまでもない。本実施例では光磁気記録を用いた場合を説明したが、追記型に適用しても同一形状の磁区を高精度に形成できる。

【0019】(実施例2) 本発明において用いたディスクは、紫外線硬化型樹脂により凹凸の案内溝を形成した12インチサイズのガラス基板上に、ニトロセルロース層を形成した。その上に、PbTeSe記録層を形成し、記録層が内側となるように中空構造となるようにして組立てた(エヤーサンドイッチ構造)ものを用いた。このタイプのディスクは、穴あけ型の追記型の光ディスクである。このディスクにユーザー情報を記録するのに先だってテスト記録を行なった。テスト記録に用いたパターンを図9に示す。この記録膜の記録温度は約450℃である。ここで、1つのパターンを記録するのに、微小分割パルスに分かれたマルチパルスを用いた。本実施例では、変調方式として(1,7)RLL方式によるマーク長記録方式を用いた。最長パターンは8Tw、最短パターンは2Twである。ディスクの回転数は1200rpmである。そして、最長パターンを5回繰返した後に、最短パターンを5個繰返したものを1周期として、パワーを標準パワーを中心に±10%づつずらして全部で5点について記録を行なった。そして、それを再生してジッタ及び標準偏差を求め、これらの値が一定の値以下になる記録条件(主にレーザーパワー)を探した。ジッタ及び標準偏差の測定にはタイムインターベルアナライザーを用いた。その結果、ジッタは±3ns以下に抑制できた。ところで、この最適な条件にて記録した場合、最短パターンと最長パターンのそれぞれの振幅の中央値は一致した。このことは、最短パターンと最長パターンの振幅の中央値を求めることは、ジッタ及び標準偏差を求めたのと同一の効果及び制御性を有していることが分かる。本発明の記録手法を用いると常に最適条件にて記録ができるので、同一形状の記録ドメインが形成されていることが分かった。この点については、走査型電子顕微鏡観察及び電気信号評価により確かめたところ、良好形状の記録ドメインが形成されていることがわかった。形成された記録ドメインは、最長ドメインも最短ドメインとも同じ幅であり、特に、最長ドメインにおいては、ドメイン幅一定化が図れていることが電気信号の面からも、ドメイン観察の面からも確認することができた。電気信号の面からは、ドメイン側の振幅がほぼ一定値になっていることにより分かる。ここで述べた光ディスクのタイプは穴あけ型のものを例に取り上げたが、本発明の効果は光ディスクのタイプに依存するものではなく、合金型、相変化型、バブル形成型のいずれのタイプのディスクでもよい。また、記録パルスにマルチパルスを用いたのは、記録媒体内の熱流を制御するためである。これによりドメイン幅一定化を実現できる。パルス幅やギャップ幅は、記録膜の熱伝導率に依存させて変化させれば良いことは言うまでもない。

【0020】

【発明の効果】本発明によれば、記録再生装置及び記録媒体の使用環境条件が変動しても、テスト記録を行なうことにより、常に最適条件にてディスクへ記録を行なう(同一形状の磁区を高精度に形成できる)ことができる。また、ディスクの積層構造が異なっても(ディスクの記録条件が異なる)テスト記録を行なうことにより、常に最適条件にてディスクへ記録を行なう(同一形状の磁区を高精度に形成できる)ことができる。特に、テスト記録の結果から、最適の記録条件を決定するのに記録パルスのパルス幅を制御することにより、微調整が可能となるとなり、形成される記録磁区の制御精度を大きく向上させることができる。その結果、使用環境の変動やディスクの構造の違いによる記録条件の変動をキャンセルできるので、微小磁区を安定に且つ同一のサイズにディスクへ記録できるので、超高密度光磁気記録、或いは、超高密度追記型光記録を実現できる。

【0021】追記型光ディスクにおいては、レーザーパワー等の記録条件が変動しても、テスト記録を行ないその結果を解析することにより、パワーの変動を検出しそれに基づいてパワーを制御できるので、常に、同じサイズの記録ドメインが形成できるので、高密度光記録を実現できた。さらに、本発明の効果は追記型の光ディスクについて有効であり、光ディスクのタイプに依存するものではなく、合金型、相変化型、バブル形成型のいずれのタイプのディスクでもよいことはいうまでもない。

【図面の簡単な説明】

【図1】光磁気ディスクの断面構造を示す模式図。

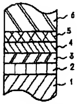
【図2】記録再生装置の構成を示す図。

【図3】記録に用いた波形を示す図。
【図4】ジッタ分布を示す図。
【図5】最長パターンと最短パターンの信号振幅の中心値の差とパルス幅との変化量を示す図。
【図6】最長パターンと最短パターンの信号振幅の中心値の差とパルス幅との変化量を示す図。
【図7】光磁気ディスクの断面構造を示す模式図。
【図8】最長パターンと最短パターンの信号振幅の中心値の差とパルス幅との変化量を示す図。
【図9】記録に用いた波形を示す図。
【符号の説明】

1…ディスク基板、2…窒化シリコン層、3…光磁気記録膜、4…窒化シリコン層、5…金属膜、6…樹脂層、101…記録媒体、102…光ヘッド、103…試し書き器、104…符号器、105…記録波形生成器、106…APC、107…レーザー駆動器、108…レーザー、109…受光器、110…再生アンプ、111…波形等化器、112…入力切替器、113…整形器、114…PLL、115…弁別器、116…比較判別器、117…復号器、120…記録符号列、121…記録パルス列、122…記録補助パルス、123…記録マーク、124…再生符号、125…再生符号列。

【図1】

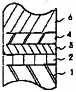
図 1



1…ディスク基板
2…窒化シリコン層
3…光磁気記録層
4…窒化シリコン層
5…金属膜
6…樹脂層

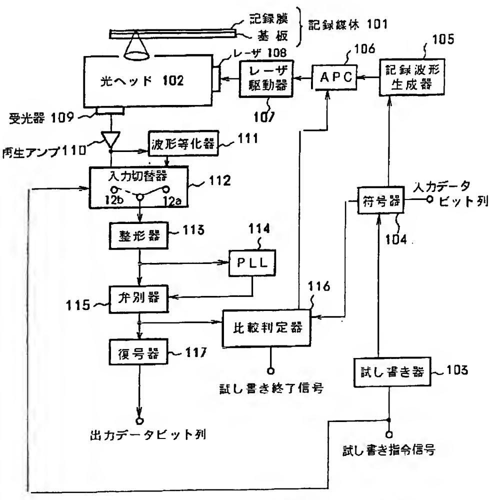
【図7】

図 7



【図2】

図 2



101 … 記録媒体
102 … 光ヘッド
103 … 試し書き器
104 … 符号器
105 … 記録波形生成器
106 … APC
107 … レーザ駆動器
108 … レーザ
109 … 受光器
110 … 再生アンプ
111 … 波形等化器
112 … 入力切替器
113 … 整形器
114 … PLL
115 … 弁別器
116 … 比較判別器
117 … 復号器

【図3】

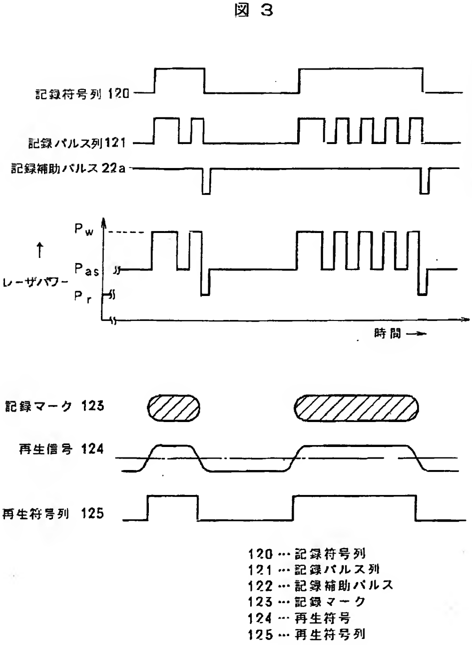


図 3
記録符号列 120
記録パルス列121
記録補助パルス 22a
Pw
Pas
Pr
レーザパワー
時間
記録マーク 123
再生信号 124
再生符号列 125
120 … 記録符号列
121 … 記録パルス列
122 … 記録補助パルス
123 … 記録マーク
124 … 再生符号
125 … 再生符号列

【図4】

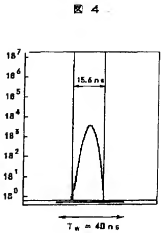
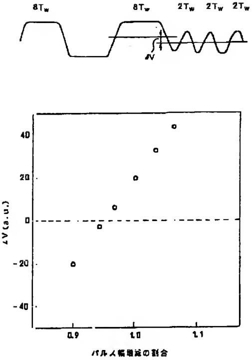


図 4
15.6 ns
Tw = 40 ns

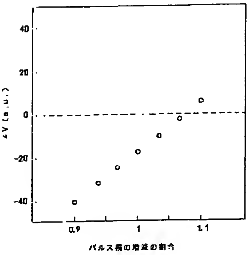
【図5】

図 5



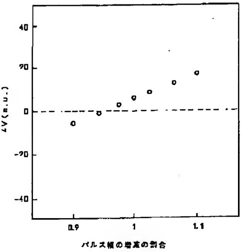
【図6】

図 6

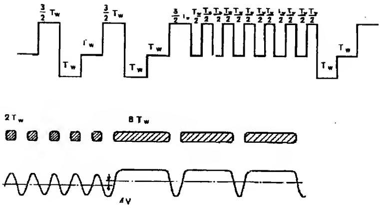


【図8】

図 8



【図9】



【手続補正書】
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【手続補正１】
【補正対象書類名】明細書
【補正対象項目名】特許請求の範囲
【補正方法】変更
【補正内容】
【特許請求の範囲】
【請求項１】光ディスクにパルス幅の変化をさせて最長パターンと最短パターンを含むテスト情報の試し書きと再生を行うレーザー光出力手段と、該再生された上記光ディスクに書き込まれた上記テスト情報の信号を入力し、該信号に信号処理を行い、該信号処理された信号中に含まれる上記最長パターンと上記最短パターンの信号振幅の中心値の差を検出する信号処理手段と、該検出された中心値の差を入力し、上記中心値の差を小さくするよう上記パルス幅を制御する制御手段と、を有する光記録装置。
【請求項２】請求項２記載の光記録装置であって、上記光ディスクのローディング時又は該光記録装置の起動時に、上記試し書きが行われることを特徴とする光記録装置。

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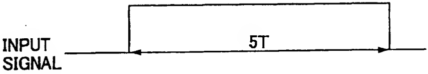
(54) Optical recording method and apparatus, and optical storage medium

(57) In an optical recording method and apparatus of the present invention, a driving power is applied to a light source to control emission of a light beam to a recording layer of an optical storage medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of a period T of a write clock. A multi-pulse waveform of each mark portion of the driving power includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe. The waveform is controlled, when a linear velocity of rotation of the medium is set in a range from 5 m/s to 28 m/s, such that the first pulse width t1 ranges 0.1T to 1T and the fourth pulse width t4 ranges 0.2T to 1.3T.

FIG.4A



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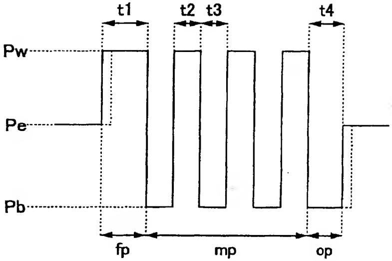
(Cont. next page)

FIG.4B



Description

BACKGROUND OF THE INVENTION

1. Field of The Invention

[0001] The present invention relates to an optical recording method and apparatus that records information onto an optical storage medium at a high speed by emitting a light beam to a recording layer of the storage medium. Further, the present invention relates to an optical storage medium that stores information recorded by using the optical recording method and apparatus.

2. Description of The Related Art

[0002] Recently, optical storage media, including CD-R (compact disk recordable), CD-RW (compact disk rewritable) and so on, become widespread. Each storage medium is provided for recording information thereon by focusing a light beam onto a recording layer of the medium and changing the phase of the recording layer material.

[0003] As disclosed in Japanese Laid-Open Patent Application No.63-29336, an optical recording method that records information onto a recording layer of an optical recording medium by emitting light to the recording layer of the medium is known. In the optical recording method of the above document, a light source driving waveform is applied to a light source to control emission of a light beam to the recording layer of the medium based on a write data modulation method. Moreover, there is known an optical recording method that determines an optimum light source driving waveform (including the write power and the write pulse width), which is applied to the light source, based on a readout signal of the recorded information derived from a reflection light beam from the optical disk.

[0004] Further, several optical recording methods have been proposed for improvement of the quality of the write signal recorded on a rewritable phase-change storage medium. For example, Japanese Laid-Open Patent Application No.63-266632 discloses such improvement method. In the conventional method of the above document, a pulse width modulation (PWM) method is utilized for application of a multi-pulse light source driving waveform to the light source to control emission of a light beam from the light source to a rewritable phase-change optical disk having a recording layer with a large crystallization speed. The conventional method provides the driving waveform that is effective in recording a long amorphous mark on the recording layer of the optical disk.

[0005] In addition, Japanese Laid-Open Patent Application No.63-266633 and United States Patent No. 5150352 disclose an optical recording method which eliminates positional variations of a mark edge and improves the jitter characteristics of an optical disk by applying a driving waveform including a front-end portion or a tail-end portion having an increased pulse width or with an increased power level to the light source.

[0006] Further, the rewritable compact disk standards (the orange book, part III, ver. 2.0) provide the recommended specifications of 1X to 4X linear velocity recording of the rewritable recording media. The linear velocities 1X to 4X according to the standards (the orange book, part III, ver. 2.0) range from 1.2 m/s to 5.6 m/s. The recording speeds of the media in this range require a relatively long time to record information onto the media. There is an increasing demand for a reliable CD-RW drive that is able to carry out error-free information recording with good write-erase characteristics at higher recording speeds. Preparations of high-speed specifications of 4X to 10X linear velocity recording for the rewritable compact disk standards are now under way. The linear velocities 4X to 10X according to the standards (the orange book, part III) range from 5 m/s to 28 m/s.

[0007] Accordingly, it is desirable to provide an optical recording method and apparatus that ensures good write/erase characteristics of the rewritable phase-change medium and retains the compatibility with the write-once storage medium when high-speed recording (equivalent to the 4X to 10X linear velocity recording) is performed. The conventional recording methods and devices of the above documents are not yet adequate to attain the goal.

SUMMARY OF THE INVENTION

[0008] It is a general object of the present invention to provide an optical recording method and apparatus in which the aforementioned problems are eliminated.

[0009] Another object of the present invention is to provide an optical recording method and apparatus that ensures good write/erase characteristics of the rewritable phase-change medium and retains the compatibility with the write-once storage medium when high-speed recording is performed.

[0010] Another object of the present invention is to provide an optical recording method and apparatus that provides increases of initial characteristics and overwrite performance of the rewritable phase-change medium.

[0011] Another object of the present invention is to provide an optical storage medium that stores information recorded by using the optical recording method and apparatus such that good write/erase characteristics of the rewritable phase-change medium are ensured and the compatibility with the write-once storage medium is retained when high-speed recording is performed.

[0012] The above-mentioned objects of the present invention are achieved by an optical recording method which records a sequence of data blocks onto a recording layer of an optical recording medium by emitting light to the recording layer of the medium and changing a

phase of a recording material of the recording layer, the method comprising the steps of: applying a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of a period T of a write clock based on a write data modulation method; setting a multi-pulse waveform of each mark portion of the driving power that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe; setting a linear velocity of rotation of the medium at a controlled speed; and controlling the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T.

[0013] The above-mentioned objects of the present invention are achieved by an optical recording apparatus which records a sequence of data blocks onto a recording layer of an optical recording medium by emitting light to the recording layer of the medium and changing a phase of a recording material of the recording layer, the apparatus comprising: a light source driver unit which applies a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of a period T of a write clock based on a write data modulation method; a write power determination unit which sets a multi-pulse waveform of each mark portion of the driving power that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe; and a controller which sets a linear velocity of rotation of the medium at a controlled speed, wherein the controller causes the write power determination unit to control the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T.

[0014] The above-mentioned objects of the present invention are achieved by an optical storage medium which stores information recorded by using an optical recording method that records a sequence of data blocks onto a recording layer of an optical recording medium by emitting light to the recording layer of the medium and changing a phase of a recording material of the recording layer, the optical recording method comprising the steps of: applying a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of a period T of a write clock based on a write data modulation method; setting a multi-pulse waveform of each mark portion of the waveform that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe; setting a linear velocity of rotation of the medium at a controlled speed; and controlling the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T, the optical storage medium comprising the sequence of data blocks recorded on the recording layer, each data block including first information indicative of the first pulse width t1 of the front-end portion and second information indicative of the fourth pulse width t4 of the tail-end portion in the light source driving waveform.

[0015] In the optical recording method and apparatus of the present invention, the driving power is applied to the light source to control emission of a light beam to the recording layer of the optical storage medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of the period T of the write clock. The waveform of each mark portion of the driving power includes the front-end portion, the multi-pulse portion and the tail-end portion, the front-end portion having the first pulse width t1 with the write level Pw and starting from the erase level Pe, the multi-pulse portion including the write pulses each having the second pulse width t2 with the write level Pw and the third pulse width t3 with the base level Pb, the multi-pulse portion having the duty ratio z = t2/(t2 + t3), and the tail-end portion having the fourth pulse width t4 with the base level Pb and ending at the erase level Pe. The waveform is controlled, when

the linear velocity of rotation of the medium is set in a range from 5 m/s to 28 m/s, such that the first pulse width t1 ranges 0.1T to 1T and the fourth pulse width t4 ranges 0.2T to 1.3T. As the front-end edge and the tail-end edge of each mark (the amorphous phase) are accurately and definitely created on the recording layer of the rewritable phase-change medium when high-speed recording is performed, the optical recording method and apparatus of the present invention can ensure good write/erase characteristics of the rewritable phase-change medium and retain the compatibility with the write-once storage medium when high-speed recording is performed. The optical recording method and apparatus of the present invention are effective in increasing the initial characteristics and the overwrite performance of the rewritable phase-change medium.

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Other objects, features and advantages of the present invention will become apparent from the following detailed description when read in conjunction with the accompanying drawings.

[0017] FIG. 1 is a cross-sectional diagram of one preferred embodiment of the optical storage medium of the invention.

[0018] FIG. 2 is a diagram for explaining a characteristic of storage medium's reflectivity with respect to relative velocity and a characteristic of the differential coefficient of the reflectivity with respect to relative velocity.

[0019] FIG. 3 is a block diagram of one preferred embodiment of the optical recording apparatus of the invention.

[0020] FIG. 4A and FIG. 4B are waveform diagrams for explaining a multi-pulse laser driving waveform used by the optical recording apparatus of FIG. 3.

[0021] FIG. 5 is a diagram for explaining the dependence of the write signal asymmetry on the front-end pulse width and the tail-end pulse width of the multi-pulse waveform.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

[0022] A description will now be provided of preferred embodiments of the present invention with reference to the accompanying drawings.

[0023] FIG. 1 is a cross-sectional diagram of one preferred embodiment of the optical storage medium of the invention.

[0024] The optical storage medium of the present embodiment is a rewritable phase-change medium (CD-RW) in which a recording layer of a phase-change material is formed on a substrate. As shown in FIG. 1, in the storage medium 1 of this embodiment, a substrate 2, a lower protective layer 3, a recording layer 4, an upper protective layer 5, and a reflection/heat-radiation layer 6 are provided. The lower protective layer 3, the recording layer 4, the upper protective layer 5 and the reflection/heat-radiation layer 6 are deposited, in this order, on the front surface of the substrate 2. Further, an over-coat layer 7 may be provided on the reflection/heat-radiation layer 6, and a hard-coat layer 8 may be provided on the back surface of the substrate 2.

[0025] In the medium 1 of the present embodiment, the substrate 2 is provided in order to support the recording layer 4. When a read/write laser beam emitted by a laser light source is incident to the substrate 2 of the storage medium 1, the substrate 2 must be transparent to the incident laser beam having a wavelength of the read/write laser beam used. A suitable transparent material of the substrate 2 is selected from among glass materials, ceramics materials and resin materials. Resin materials are more suitable for the substrate 2 because of the transparency and the ease of molding.

[0026] A suitable resin material of the substrate 2 may be selected from one of resin materials including polycarbonate resins, acrylic resins, epoxy resins, polystyrene resins, styrene-acrylonitrile copolymer resins, polyethylene resins, polypropylene resins, silicon-based resins, fluorine-based resins, acrylonitrile-butadiene-styrene (ABS) resins and urethane resins. In particular, polycarbonate resins or acrylic resins are selected as a more suitable material of the substrate 2, because of the ease of molding, the required optical characteristics and the cost effectiveness. A set of guide grooves may be provided on the transparent substrate 2.

[0027] In the storage medium 1 of the present embodiment, the lower and upper protective layers 3 and 5 are made of a dielectric material because of the required thermal and optical characteristics. A suitable material of the protective layers 3 and 5 may be selected from a single-component or mixture dielectric materials including oxides of SiO_2, SiO, ZnO, SnO_2, TiO_2, InO_2, Mg, ZrO_2, etc., nitrides of Si_3N_4, AlN, TiN, BN, ZrN, etc., sulphides of ZnS, In_2S_3, TaS_4, etc., carbides of SiC, TaC, B4C, WC, TiC, ZrC, etc., and diamond-state carbon. The lower and upper protective layers 3 and 5 are deposited by using physical vapor deposition, sputtering, ionplating, or chemical vapor deposition. Because of the productivity and the cost, sputtering is selected as the more suitable one for the formation of the lower and upper protective layers 3 and 5. An optimum thickness of the protective layers 3 and 5 may be determined in view of the required thermal and optical characteristics. Typically, the thickness of the protective layers 3 and 5 ranges from 10 nm to 5000 nm.

[0028] In the storage medium 1 of the present embodiment, the recording layer 4 is made of a phase-change material. A suitable phase-change material of the recording layer 4 may be selected from alloy-based phase-change materials including GeTe, GeTeSe, GeTeS, GeSeSb, GeAsSe, InTe, SeTe, SeAs, Ge-Te-(Sn, Au, Pd), GeTeSeSb, GeTeSb, AgInSbTe, etc. The composition of elemental substances in each phase-change material may be optimized in accordance with

a linear velocity of rotation of the medium. A small amount of impurities, selected from substances including B, N, C, O, Si, P, S, Ge, Se, Al, Ti, Zr, V, Mn, Fe, Co, Ni, Cr, Cu, Zn, Sn, Pd, Pt, Au, etc., may be mixed with the phase-change material of the recording layer 4.

[0029] Specifically, the selection of AgInSbTe as the phase-change material of the recording layer 4 is more suitable because it provides definite boundaries between crystalline areas and non-crystalline (or amorphous) areas, which suits to a mark-edge recording technique (which will be described later) that is used by the optical recording method and apparatus of the present invention. A small amount of impurities (for example, N) may be added to the phase-change material, which allows a margin of the linear velocity of the medium rotation to be increased.

[0030] In the storage medium 1 of the present embodiment, the composition of the phase-change material (AgInSbTe) of the recording layer 4 is represented by the formula $Ag_\alpha In_\beta Sb_\gamma Te_\delta$

$$0.1 \leqq \alpha \leqq 3.0$$

$$5.0 \leqq \beta \leqq 12.0$$

$$60.0 \leqq \gamma \leqq 72.0$$

$$22.0 \leqq \delta \leqq 30.0.$$

A desired thickness of the phase-change material of the recording layer 4 ranges from 13 nm to 17 nm. With the above composition and the above thickness of the phase-change material of the recording layer 4, the present embodiment can ensure good write/erase characteristics of the rewritable phase-change medium and retain the compatibility with the write-once storage medium even when high-speed recording is performed.

[0031] In the storage medium 1 of the present embodiment, the recording layer 4 is deposited on the substrate 2 by using physical vapor deposition, sputtering, ionplating, or chemical vapor deposition. Because of the productivity and the cost, sputtering is selected as the more suitable one for the formation of the recording layer 4.

[0032] Further, in the storage medium 1 of the present embodiment, the reflection/heat radiation layer 6 serves to reflect the read/write light beam and dissipate heat produced during recording. A suitable material of the reflection/heat radiation layer 6 may be selected from single-component metals including Ag, Au, Al, or mixture alloys including Ti, Si, Cr, Ta, Cu, Pd, C, etc. Preferably, the reflection/heat radiation layer 6 is made of an aluminum-based alloy because of the required thermal and optical characteristics and the productivity. A desired composition of the material of the reflection/heat radiation layer 6 and a desired thickness of the reflection/heat radiation layer 6 may be determined in view of the required thermal and optical characteristics.

[0033] In the storage medium 1 of the present embodiment, the over-coat layer 7 is made of a resin material containing, as the major component, an optical curing resin or an electron beam curing resin. Because of the ease of curing and the ease of film formation, a resin material containing, as the major component, a UV (ultraviolet ray) curing resin is more suitable for the material of the over-coat layer 7. The film formation of the over-coat layer 7 is performed by using a dipping method or a spin-coat method.

[0034] In order to conform to the high-speed specifications of 4X to 10X linear velocity recording for the expected rewritable compact disk standards, it is necessary that the optical storage medium 1 of the present embodiment be configured to meet the conditions related to the phase-change critical linear velocity (which will be called the velocity "vo").

[0035] Suppose that a measuring device (or a pickup) for measuring the phase-change critical linear velocity (the velocity "vo") of the medium meets the following conditions: the wavelength of a read/write laser beam emitted by the laser light source is 789 nm; and the numerical aperture (NA) of the objective lens is 0.49. Further, suppose that "v" indicates a relative velocity of the medium to the optical recording apparatus during the recording, "vwh" indicates the highest relative velocity of the medium during the recording, and "vwl" indicates the lowest relative velocity of the medium during the recording.

[0036] A measurement power "P_E" of the measuring device (or the pickup) used when measuring the velocity "vo" of the medium is defined by the formula: $P_E = 0.75\ P_{OH}$ where "P_{OH}" indicates an optimum recording power when the linear velocity "v" of the medium 1 is set at the highest linear velocity "vwh".

[0037] The measurement of the velocity "vo" is performed when the medium 1 is moved to the pickup at the relative velocity "v" and the pickup emits a write laser beam to the medium from the laser light source at the measurement power "P_E". At this time, a pulsed light source emission waveform, which is ordinarily used for the recording of conventional phase-change media, is not used for the emission of the laser beam. A direct-current (DC) driving waveform is used for the emission of the write laser beam, and a reflectivity of the recorded portion of the medium is detected based on a reflection beam from the medium by a reproducing part of the optical recording apparatus. The reflectivity obtained at this time is indicated by a variable R(v) with respect to the relative velocity "v". Suppose that the wavelength of the read laser beam is set at 789 nm.

[0038] FIG. 2 shows a characteristic of the reflectivity "R" of the medium 1 of the present embodiment with respect to the relative velocity "v" and a characteristic of

the differential coefficient "- dR/dv" of the reflectivity with respect to relative velocity "v".

[0039] As shown in FIG. 2, as the relative velocity "v" increases, the reflectivity "R" decreases from an initial saturation point "R_A". When a certain point of the relative velocity "v" is reached, the decrease of the reflectivity "R" is stopped at a secondary saturation point "R_B". Conversely, as the relative velocity "v" decreases, the reflectivity "R" increases from the secondary saturation point R_B, and when a certain point of the relative velocity "v" is reached, the increase of the reflectivity "R" is stopped at the initial saturation point R_A.

[0040] As is apparent from FIG. 2, the phase-change critical relative velocity "vo" of the medium is defined by a value of the relative velocity "v" when the differential coefficient "-dR/dv" of the reflectivity is the maximum "(-dR/dv)max" (the peak point). A margin "Δvo" of the velocity "vo" is defined by an effective range of the linear velocity "v" when the differential coefficient "-dR/dv" of the reflectivity decays to half the maximum "(-dR/dv) max".

[0041] In the storage medium 1 of the present embodiment, the phase-change material of the recording layer is selected such that it satisfies the following conditions:

$$vo \geqq 0.7vwh$$

where "vo" is the phase-change critical linear velocity, and "vwh" is the highest linear velocity.

[0042] It has been confirmed from experiments that, when the optical storage medium 1 of the present embodiment is configured to meet the above conditions (in other words, the velocity "vo" of the medium 1 is set to satisfy the above conditions), the medium 1 provides good write/erase characteristics as well as improved overwrite performances when the recording is performed at the highest linear velocity "vwh".

[0043] On the other hand, when the medium 1 does not meet the above conditions, it provides poor write/erase characteristics as well as undesired overwrite performances when the recording is performed at the highest linear velocity "vwh". The primary reason is that it is difficult that such medium 1 returns the state of a mark on the medium with the reflectivity being at the secondary saturation point R_B back to the state of a space on the medium with the reflectivity being at the initial saturation point R_A.

[0044] Further, in the storage medium 1 of the present embodiment, it is preferred that the phase-change material of the recording layer is selected such that it satisfies the following conditions:

$$vo \leqq 3.0vwl$$

where "vo" is the phase-change critical linear velocity, and "vwl" is the lowest linear velocity.

[0045] It has been confirmed from experiments that, when the optical storage medium 1 of the present embodiment is configured to meet the above conditions (in other words, the velocity "vo" of the medium 1 is set to satisfy the above conditions), the medium 1 provides good mark-formation characteristics as well as improved overwrite performances when the recording is performed at the lowest linear velocity "vwl".

[0046] The margin "Δvo" of the medium 1 indicates the tendency of deterioration of the recording signal at the highest linear velocity "vwh". In the storage medium 1 of the present embodiment, it is preferred that the phase-change material of the recording layer is selected such that it satisfies the following conditions:

$$\Delta vo/vo < 0.4$$

where "vo" is the phase-change critical linear velocity, and "Δvo" is the margin of the velocity "vo".

[0047] It has been confirmed from experiments that, when the optical storage medium 1 of the present embodiment is configured to meet the above conditions (in other words, the velocity "vo" of the medium 1 is set to satisfy the above conditions), the medium 1 provides improved stability of write/erase characteristics when the recording is performed at the highest linear velocity "vwh".

[0048] Further, in the storage medium 1 of the present embodiment, it is preferred that the phase-change material of the recording layer is selected such that it satisfies the following conditions:

$$0.1 < R_A/R_B < 0.6$$

where "R_A" is the initial saturation point of the medium, and "R_B" is the secondary saturation point of the medium.

[0049] It has been confirmed from experiments that, when the optical storage medium 1 of the present embodiment is configured to meet the above conditions, the medium 1 provides a good mark/space contrast when the recording is performed.

[0050] Further, in the storage medium 1 of the present embodiment, it is preferred that the phase-change material of the recording layer is selected such that it satisfies the following conditions:

$$vwh/vwl \geqq 2.5$$

where "vwh" is the highest linear velocity of the medium during the recording, and "vwl" is the lowest linear velocity of the medium during the recording.

[0051] It has been confirmed from experiments that, when the optical storage medium 1 of the present embodiment is configured to meet the above conditions, it

makes it possible to perform the constant angular velocity (CAV) recording of a 120-mm diameter optical disk (currently the dominating one) in the recording linear velocities corresponding to the disk recording areas ranging from 46.5 mm diameter to 116 mm diameter.

[0052] FIG. 3 shows one preferred embodiment of the optical recording apparatus of the invention. The optical recording apparatus of the present embodiment is configured to conform to the high-speed specifications of 4X to 10X linear velocity recording for the expected rewritable compact disk standards.

[0053] As shown in FIG. 3, in the optical recording apparatus of the present embodiment, the optical storage medium 1 is held on and rotated by a spindle motor 11. A controller (CTRL)16 controls the spindle motor 11 so that the linear velocity of rotation of the medium 1 is set at a controlled speed. A pickup 12 having a laser light source (for example, a laser diode) and optical systems (for example, a focusing lens and an objective lens) is provided to focus a laser beam, emitted by the light source, onto the recording layer of the medium 1 and change the phase of the recording material of the layer. The pickup 12 includes a photodetector which detects a reflection laser beam reflected from the recording layer of the medium 1 and outputs a readout signal based on the reflection laser beam.

[0054] In the optical recording apparatus of FIG. 3, a laser diode driver (LDD) 13 is provided to apply a laser driving power to the light source of the pickup 12 to control the emission of a laser beam to the recording layer of the medium 1. When recording of the medium 1 is performed, the LDD 13 applies the driving power to the light source of the pickup 12, and the light source emits the laser beam to the recording layer of the medium 1 to change the phase of the recording material of the layer. When reproducing of the medium 1 is performed, the photodetector of the pickup 12 detects the reflection laser beam reflected from the recording layer of the medium 1 and outputs the readout signal based on the reflection laser beam. In the optical recording apparatus of the present embodiment, the readout signal output by the photodetector of the pickup 12 is used to carry out the reproducing of the recorded information, the tracking servo control and the focusing servo control.

[0055] In the optical recording apparatus of FIG. 3, during the recording of the medium 1, the readout signal output by the pickup 12 is supplied to a write power monitoring unit (WPMU) 14. The write power monitoring unit 14 monitors the readout signal received from the pickup 12. A write power calculating unit (WPCU) 15 is provided to calculate the power (or the amplitude) of the readout signal and outputs the calculation result (the calculated power) to the controller 16. The controller 16 has a CPU (central processing unit), which controls the elements of the optical recording apparatus of the present embodiment. As described above, the controller 16 controls the rotating speed of the spindle motor 12 so that the linear velocity of rotation of the medium 1 is set at a controlled speed.

[0056] In the optical recording apparatus of FIG. 3, a write power determination unit (WPDU) 17 is provided to set a multi-pulse waveform of the laser driving power that is applied to the pickup 12. The controller 16 outputs a control signal to the WPDU 17 based on the feedback result (or the calculated power) from the MPCU 15, so that the WPDU 17 outputs a selected one of a test writing power (TWP) set signal and an optimum writing power (OWP) set signal to the LDD 13.

[0057] In the optical recording apparatus of the present embodiment, the pickup 12, the LDD 13, the WPDU 17 and the controller 16 form an optical information recording means 18. The optical information recording means 18 carries out a mark-edge recording process for the storage medium 1 wherein a sequence of data blocks (also called the write information), which corresponds to a sequence of mark and space portions of the driving power, are recorded onto the recording layer of the medium 1, each of the mark portions having a pulse width corresponding to a multiple of a period (T) of a write clock based on a PWM (pulse width modulation) method. In a case of the rewritable phase-change medium (CD-RW), the optical information recording means 18 converts each data block in the write information into a power level and a pulse width in the driving waveform by using an EFM (eight to fourteen modulation) process or another improved modulation technique based on the period T of the write clock.

[0058] In the optical recording apparatus of the present embodiment, the WPDU 17 sets a multi-pulse laser waveform of the driving power in order to control the emission of a laser beam by the laser light source of the pickup 12 to the recording layer of the medium 1 (CD-RW). FIG. 4A and FIG. 4B are waveform diagrams for explaining the multi-pulse laser driving waveform used by the optical recording apparatus of FIG. 3.

[0059] FIG. 4A shows the waveform of a 5T input signal where "T" indicates the period of the write clock in the optical recording apparatus of FIG. 3. The "5T" input signal means that this pulsed signal has a pulse width that is 5 times the period T of the write clock. In the example of FIG. 4A, the high-level signal portion represents "1" of the write information and corresponds a mark on the recording layer of the medium 1, and the low-level signal portions represent "0" of the write information and correspond to spaces on the recording layer of the medium 1.

[0060] FIG. 4B shows an example of the multi-pulse laser driving waveform that is set by the WPDU 17 of the present embodiment in response to the input signal of FIG. 4A.

[0061] As shown in FIG. 4A and FIG. 4B, the multi-pulse waveform, supplied from the WPDU 17 to the LDD 13, includes a front-end portion "fp", a multi-pulse portion "mp" and a tail-end portion "op". The front-end portion "fp" has a first pulse width "t1" with a high-power write level "Pw" and starts from a middle-power erase

level "Pe". The multi-pulse portion "mp" includes a sequence of write pulses each having a second pulse width "t2" with the write level Pw and a third pulse width "t3" with a low-power base level "Pb". Suppose that the conditions: Pb < Pe < Pw are met. The multi-pulse portion "mp" has a given duty ratio z = t2/(t2 + t3). The tail-end portion "op" has a fourth pulse width "t4" with the base level Pb and ends at the erase level Pe.

[0062] Generally, when one of the mark portions of the driving power is supplied to the light source of the pickup 12, a non-crystalline area (the amorphous phase) that represents "1" of the write information is formed as a mark on the recording layer of the medium 1 by the emission of a laser beam from the light source to the medium 1. The formation of the amorphous phase of the recording material on the recording layer of the medium 1 requires heating of the recording layer to an increased temperature above the melting point of the recording material and cooling of the recording layer for an adequate time after the heating.

[0063] In the waveform of FIG. 4B, the front-end portion "fp", which has the first pulse width t1 with the high-power write level Pw, provides the recording layer of the medium 1 with the energy needed to heat it to the increased temperature above the melting point. The multi-pulse portion "mp", which includes the sequence of write pulses each having the second pulse width t2 with the write level Pw and the third pulse width t3 with the base level Pb, provides the recording layer with the energy needed to form the mark thereon. Hence, if the first pulse width t1 is set at an optimum value and the waveform of the present embodiment is applied, a front-end edge of the mark can be accurately and definitely formed on the recording layer of the medium 1.

[0064] Further, in the waveform of FIG. 4B, the tail-end portion "op", which has the fourth pulse width t4 with the low-power base level Pb, serves to cool the recording layer of the medium 1 for an adequate time after the heating. Hence, if the fourth pulse width t4 is set at an optimum value and the waveform of the present embodiment is applied, a tail-end edge of the mark can be accurately and definitely formed on the recording layer of the medium 1.

[0065] It is necessary to take into consideration the above points, in order to provide good write/erase characteristics of the rewritable phase-change media when high-speed recording (equivalent to the 4X to 10X linear velocity recording) is performed. To attain the objective of the present invention, the optical recording apparatus of the present embodiment is configured such that the controller 16 causes the write power determination unit (WPDU) 17 to control the multi-pulse waveform of FIG. 4B when the linear velocity of rotation of the medium 1 is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width "t1" of the front-end portion "fp" ranges 0.1T to 1T and the fourth pulse width "t4" of the tail-end portion "op" ranges 0.2T to 1.3T. Optimum values of the first pulse width t1 and the fourth pulse width t4 vary depending on the recording material of the recording layer of the medium 1.

[0066] Experiments have been performed to ascertain the advantages of the optical recording apparatus of the present embodiment that is configured as described above. FIG. 5 shows the dependence of the write signal asymmetry on the front-end pulse width "t1" and the tail-end pulse width "t4" of the multi-pulse waveform.

[0067] In the present embodiment, the controller 16 causes the WPDU 17 to control the waveform when the linear velocity of rotation of the medium 1 is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T. In order to examine the performances of high-speed recording, the experiments are performed under the following conditions.

[0068] A CD-RW disk that is provided in conformity with the above-described embodiment of the optical storage medium of the invention is used for the experiments, and the CD-RW disk is called the medium 1. The wavelength of a laser beam emitted by the laser light source of the pickup 12 in the optical recording apparatus is 780 nm. The numerical aperture (NA) of the objective lens of the pickup 12 is set at 0.5. A high-speed recording of the medium 1 is performed at 9.6 m/s linear speed (which is equivalent to 8X linear velocity of the rewritable compact disk standards).

[0069] As shown in FIG. 5, when performing the experiments, the first pulse width "t1" of the front-end portion "fp" of the multi-pulse waveform is sequentially changed to one among 0.1T, 0.4T, 0.7T and 1.0T, and, at the same time, the fourth pulse width "t4" of the tail-end portion "op" of the multi-pulse waveform is changed to one among 0.2T, 0.5T, 0.8T, 1.0T and 1.3T with respect to each of the respective first pulse width values. By performing the experiments, the dependence of the write signal asymmetry on the front-end pulse width "t1" and the tail-end pulse width "t4" of the multi-pulse waveform is evaluated. FIG. 5 shows such results of the evaluations. Generally, the write signal asymmetry indicates the degree of asymmetry of mark length and space length, and it is represented by a normalized value obtained by dividing a difference between the average level of the radio-frequency (RF) signal amplitude of the longest mark and the average level of the RF signal amplitude of the shortest mark by the RF signal amplitude of the longest mark.

[0070] The specifications of the rewritable compact disk standards provide the requirements: -15 ≦ asymmetry ≦ 5. As is apparent from the characteristics of FIG. 5, in order to meet the requirements, it is necessary that the front-end pulse width "t1" of the multi-pulse waveform ranges from 0.1T to 1.0T and the tail-end pulse width "t4" of the multi-pulse waveform ranges from 0.2T to 1.3T.

[0071] In another preferred embodiment of the optical

recording method and apparatus of the invention, the optical storage medium 1 is prepared, in advance, to contain a sequence of data blocks recorded on the recording layer, each data block including first information indicative of the first pulse width t1 of the front-end portion "fp" and second information indicative of the fourth pulse width t4 of the tail-end portion "op" in the multi-pulse waveform. In the present embodiment, optimum values of the first pulse width t1 and the fourth pulse width t4 that are suited to a specific phase-change material of each individual medium 1 are predetermined. And, wobbling grooves or the like, carrying both the first information and the second information are formed on the medium 1.

[0072] In the optical recording method and apparatus of the present embodiment, prior to a start of the recording of the medium 1, a test writing process is performed in which test data blocks are recorded onto a test-write region (for example, a power calibration area PCA) of the medium 1 and a readout signal is detected from the test-write region of the medium 1, the readout signal indicative of the first information and the second information related to the test data blocks. Further, optimum values of the first pulse width t1 and the fourth pulse width t4 are calculated based on the first information and the second information indicated by the readout signal. In the present embodiment, the multi-pulse waveform is controlled based on the optimum values of the first pulse width tl and the fourth pulse width t4.

[0073] According to the above-described embodiment, the optimum values of the first pulse width t1 and the fourth pulse width t4 in the multi-pulse waveform can be suitably determined. As the recording of the medium 1 can be performed in the optimum conditions, the optical recording method and apparatus of the present embodiment are effective in preventing the occurrence of a read error after the recording of the medium 1 is performed, due to deterioration of the write signal quality of the medium 1.

[0074] Further, for the sake of convenience of the users, it is preferred to make commercially available the optical storage medium 1 that is formatted, in advance, to contain the first information indicative of the first pulse width t1 of the front-end portion "fp" and the second information indicative of the fourth pulse width t4 of the tail-end portion "op" in the multi-pulse waveform. The formatted medium 1 of the present embodiment provides the users with the ease-to-use feature as well as good write/erase characteristics of the rewritable phase-change medium when the high-speed recording is performed.

[0075] The present invention is not limited to the above-described embodiments, and variations and modifications may be made without departing from the scope of the present invention.

[0076] Further, the present invention is based on Japanese priority application No.2000-058399, filed on March 3, 2001, the entire contents of which are hereby incorporated by reference.

Claims

1. An optical recording method which records a sequence of data blocks onto a recording layer of an optical recording medium by emitting light to the recording layer of the medium and changing a phase of a recording material of the recording layer, comprising the steps of:

   applying a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of a period T of a write clock based on a write data modulation method;
   setting a multi-pulse waveform of each mark portion of the driving power that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe;
   setting a linear velocity of rotation of the medium at a controlled speed; and
   controlling the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T.

2. An optical recording method which records a sequence of data blocks onto a recording layer of a rewritable optical recording medium by emitting light to the recording layer of the medium and changing a phase of a recording material of the recording layer, comprising the steps of:

   applying a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark portion having a pulse width that corresponds to a multiple of a period T of a write clock based on a pulse width modulation method;

setting a multi-pulse waveform of each mark portion of the driving power that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe;

setting a linear velocity of rotation of the medium at a controlled speed; and.

controlling the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T.

3. The optical recording method according to claim 1, wherein the optical storage medium contains the sequence of data blocks recorded on the recording layer, each data block including first information indicative of the first pulse width t1 of the front-end portion and second information indicative of the fourth pulse width t4 of the tail-end portion in the waveform.

4. The optical recording method according to claim 3, further comprising the steps of:

performing a test writing process in which test data blocks are recorded onto a test-write region of the medium and a readout signal is detected from the test-write region of the medium, the readout signal indicative of the first information and the second information related to the test data blocks; and

calculating optimum values of the first pulse width t1 and the fourth pulse width t4 based on the first information and the second information indicated by the readout signal, wherein, in said controlling step, the waveform is controlled based on the optimum values of the first pulse width t1 and the fourth pulse width t4.

5. An optical recording apparatus for recording a sequence of data blocks onto a recording layer of an optical recording medium by emitting light to the recording layer of the medium and changing a phase of a recording material of the recording layer, comprising:

a light source driver unit applying a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of a period T of a write clock based on a write data modulation method;

a write power determination unit setting a multi-pulse waveform of each mark portion of the driving power that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe; and

a controller setting a linear velocity of rotation of the medium at a controlled speed,

wherein the controller causes the write power determination unit to control the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T.

6. An optical recording apparatus for recording a sequence of data blocks onto a recording layer of a rewritable optical recording medium by emitting light to the recording layer of the medium and changing a phase of a recording material of the recording layer, comprising:

a light source driver unit applying a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of a period T of a write clock based on a pulse width modulation method;

a write power determination unit setting a multi-pulse waveform of each mark portion of the driving power that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width

t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe; and
a controller setting a linear velocity of rotation of the medium at a controlled speed,
wherein the controller causes the write power determination unit to control the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T.

7. The optical recording apparatus according to claim 5, wherein the optical storage medium contains the sequence of data blocks recorded on the recording layer, each data block including first information indicative of the first pulse width t1 of the front-end portion and second information indicative of the fourth pulse width t4 of the tail-end portion in the waveform.

8. The optical recording apparatus according to claim 7, wherein the controller performs a test writing process in which test data blocks are recorded onto a test-write region of the medium and a readout signal is detected from the test-write region of the medium, the readout signal indicative of the first information and the second information related to the test data blocks, wherein the controller causes a write power calculating unit to calculate optimum values of the first pulse width t1 and the fourth pulse width t4 based on the first information and the second information indicated by the readout signal.

9. An optical storage medium which stores information recorded by using an optical recording method that records a sequence of data blocks onto a recording layer of an optical recording medium by emitting light to the recording layer of the medium and changing a phase of a recording material of the recording layer, the optical recording method comprising the steps of:

applying a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark potion having a pulse width that corresponds to a multiple of a period T of a write clock based on a write data modulation method;
setting a multi-pulse waveform of each mark portion of the driving power that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe;
setting a linear velocity of rotation of the medium at a controlled speed; and
controlling the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T,
said optical storage medium comprising the sequence of data blocks recorded on the recording layer, each data block including first information indicative of the first pulse width t1 of the front-end portion and second information indicative of the fourth pulse width t4 of the tail-end portion in the waveform.

10. An optical storage medium which stores information recorded by using an optical recording method that records a sequence of data blocks onto a recording layer of a rewritable optical recording medium by emitting light to the recording layer of the medium and changing a phase of a recording material of the recording layer, the optical recording method comprising the steps of:

applying a light source driving power to a light source to control emission of a light beam to the recording layer of the medium, the driving power including a sequence of mark and space portions, each mark portion having a pulse width that corresponds to a multiple of a period T of a write clock based on a pulse width modulation method;
setting a multi-pulse waveform of each mark portion of the driving power that includes a front-end portion, a multi-pulse portion and a tail-end portion, the front-end portion having a first pulse width t1 with a high-power write level Pw and starting from a middle-power erase level Pe, the multi-pulse portion including a sequence of write pulses each having a second pulse width t2 with the write level Pw and a third pulse width t3 with a low-power base level Pb, the multi-pulse portion having a given duty ratio z = t2/(t2 + t3), and the tail-end portion having a fourth pulse width t4 with the base level Pb and ending at the erase level Pe;

setting a linear velocity of rotation of the medium at a controlled speed; and

controlling the waveform when the linear velocity of rotation of the medium is set in a high-speed range from 5 m/s to 28 m/s, such that the first pulse width t1 of the front-end portion ranges 0.1T to 1T and the fourth pulse width t4 of the tail-end portion ranges 0.2T to 1.3T,

said optical storage medium comprising the sequence of data blocks recorded on the recording layer, each data block including first information indicative of the first pulse width t1 of the front-end portion and second information indicative of the fourth pulse width t4 of the tail-end portion in the light source driving waveform.

FIG.1

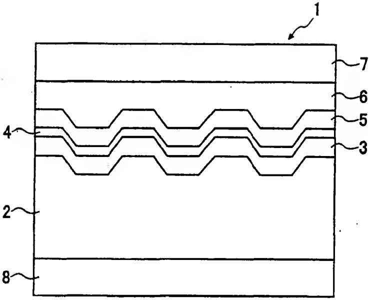


FIG.2

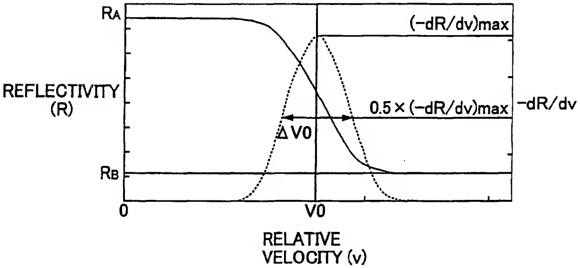
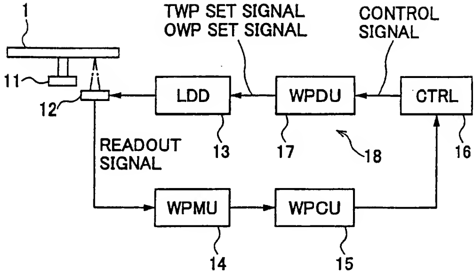

RA
RB
REFLECTIVITY (R)
(-dR/dv)max
0.5 × (-dR/dv)max
-dR/dv
ΔV0
0
V0
RELATIVE VELOCITY (v)

FIG.3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OWP SET SIGNAL
CONTROL
SIGNAL
11
12
LDD
WPDU
CTRL
READOUT
SIGNAL
13
17
18
16
WPMU
WPCU
14
15

FIG.4A

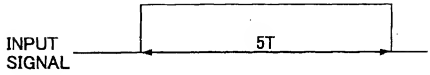


FIG.4B

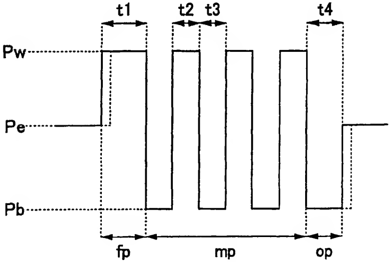
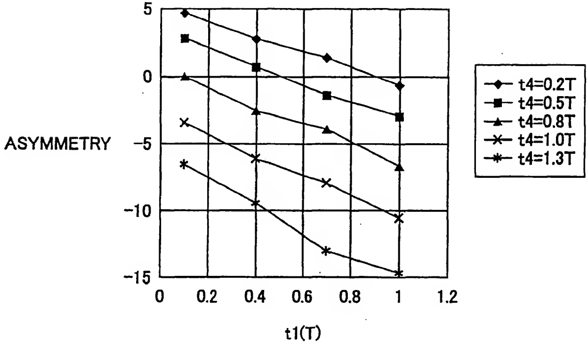


FIG.5


ASYMMETRY
5
0
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-15
0
0.2
0.4
0.6
0.8
1
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t1(T)
t4=0.2T
t4=0.5T
t4=0.8T
t4=1.0T
t4=1.3T

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 01 10 4495

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
X A	EP 0 802 531 A (HITACHI LTD) 22 October 1997 (1997-10-22) * column 20, line 22 - line 25 * * column 23, line 40 - column 24, line 37 * * column 28, line 37 - column 31, line 50; figure 14 * ---	1,2,5,6 9,10	G11B7/125 G11B7/0045
X A	EP 0 898 272 A (RICOH KK) 24 February 1999 (1999-02-24) * paragraph [0121]; figure 88; table 1 * ---	1,2,5,6 9,10	
X A	EP 0 737 962 A (RICOH KK) 16 October 1996 (1996-10-16) * abstract * * page 2, line 5 - line 7 * * page 9, line 9 - line 17 * * page 11, line 53 - line 59; figure 1 * ---	1,2,5,6 9,10	TECHNICAL FIELDS SEARCHED (Int.Cl.7)
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